RESEARCH AND TECHNOLOGY TRANSFER STRATEGIES FOR THE NEXT DECADE—AN INDIAN EXAMPLE

By

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Abstract

Globalisation is driving unprecedented, radical internal and external reforms in sugar industries across the world. In addition to this, five major emerging or intensifying forces with extraordinary implications will shape sugarcane farming and the sugar industry in future—demographic, economical, socio-political, environmental and technological. This paper first addresses the growth and status of the sugar industry and impact of these emerging forces in shaping future Indian sugarcane farming. Emerging complexities and diversities in farming structure and process demand a new and more complex model of research and technology transfer. Consolidation of the best technologies for maximum exploitation, identification of technology diffusion and adoption gaps, and introduction of new technologies and innovative practices throughout the farming chain will continue to play a vital role in sugarcane productivity improvements. Demographic changes, socioeconomic status of farmers and prices for competing crops will demand sugar companies provide, in addition to competitive cane price, targeted delivery of diverse services to farmers to ensure a sustainable cane supply. Introduction of new sustainability standards and the need for certification from consumers will drive sugar companies to integrate the entire value chain from farmer to consumer through various forms of cooperation, relationship and partnership. These emerging realities will open up untapped potentials and utilise opportunities throughout the value chain to create a new research and technology transfer architecture and competitive landscape for the sugar industry in India.

Introduction

Sugarcane, sugar beet and sugar are politically regulated agricultural crops and a commodity. However, during the past two decades, liberalisation and globalisation has been driving internal and external reforms in the sugar industry.

Sugar production has more than doubled since the 1960s and the production share from cane has increased to 78%. Regional composition of production, consumption and exports/imports has shifted considerably. Brazil, India, the European Union and China are the largest sugar producers with roughly 55% of world production. These are followed by USA, Thailand, Pakistan and Australia with 15% of production during 2007–2008. Eight of these countries are also among the top sugar consumers, representing 55% of global consumption. Historically, sugarcane research has also been concentrated in these countries.

Factors that determine the fundamentals of success and failure in sugarcane research, farming and sugar businesses have also changed. New innovative players, especially Brazil, have
demonstrated their ability to adopt these changes quickly and have dominated the world market. However, multiple utilities of sugarcane as a feedstock for production of sugar, electricity, alcohol, biofuels, bio-polymers and bio-pharmaceuticals are creating a new competitive landscape. These result in increased complexities and diversities in farming structure and process, and demand a new and more complex model of research and technology transfer. Further demographic, economical, socio-political, environmental and technological changes demand consolidation, innovation, and integration across the entire value chain.

Changing landscape

Demographic shift

Along with continued population growth, the world population is experiencing unprecedented demographic changes. People are living longer and increasing numbers are moving from villages to cities in search of a better life. United Nation’s revised estimates on population growth indicate the world population will reach 7.5 billion in 2020 (UN, 2001). All of this growth will occur in Africa, Asia and Latin America, the major cane growing areas of the world. In contrast, in the developed world, the area of major beet growers (Europe, Japan and North America), populations will either decline or remain the same. This means that the demand-supply situation of sugar will move towards the Asian, South East Asian and African countries. Presently, India is the largest consumer of sugar representing 15% of world consumption, even with its lower per capita consumption than the world average (18 kg/22 kg). A projected population of 1.3 billion in 2020 with its large working population (60% in the age group 15–64 years) and emerging young generation (36% younger than 15 years) with wide choices and life styles will push per capita sugar consumption beyond world averages.

Economic growth

Globalisation and the information technology revolution are creating dramatic changes in the economic growth pattern of the developing countries. The World Bank Global Economic Prospects (2009) forecast that the average annual growth rate over the next decade will be highest in China followed by India, Brazil and South East Asia and African countries. This will generate demand for diverse foods. These demands are expected to have a significant impact on the type of sugar consumption among the new generation elites. As a consequence, Brazil, India and China are becoming new centres of forces shaping world sugar production, consumption and trade. A nationwide survey conducted in 2007 also confirmed that there was a shift in consumption pattern of sugar from domestic to industrial use (beverages, confectionery, preserved food, etc.). Of the total sugar sold in the free market, 61% accounted for industrial and the balance of 39% for household use (KPMG, 2007).

Socio-political situation

Sugar is produced in more than 100 countries. However, sugar trade is limited to 30% of the production with long-term agreements. Various socio-political policies continue to influence sugar prices and increase volatility. WTO agreements are expected to liberate the sugar trade from some of these distortions. The major beneficiaries of these sugar reforms will be least-cost-of-production countries with potential to expand production. However, countries such as Brazil, Thailand, India, Pakistan and South Africa, where the domestic market prices are lower than the average world traded price, will face pressure from domestic consumers and political lobbies will continue to constrain price.

There is a need for production to keep pace with sugar consumption. Only Brazil has the capacity to expand the area under sugarcane; another 9 million hectares without affecting their food crops (UNICA, 2008). The Brazilian industry is expanding to capitalise on these opportunities along with its pro-alcohol flex-fuel program. Countries such as Brazil, Australia and South Africa
are more advantaged than others, because of the size of their farms, the structure of operations, and their integrated value chains.

India, with 17.5% of global population but only 2.4% of the world’s arable land, cannot further increase its area under sugarcane without replacing other food crops. Between 1960 and 2003, the number of agricultural holdings doubled (51–101 million), while the area operated declined from 133 to 108 million hectares. This has led to a sharp decline in the average size of holding (2.63 ha to 1.06 ha) leading to an increase in the number of marginal farmers (22.6 to 39.1%; marginal means <1 ha (GOI, 2007; NSSO, 2005). Increasing marginalisation leads to insecurity, increasing costs, inadequate returns, and difficulties in accessing credit. The consequence is exploitative informal credit and resulting pervasive indebtedness (Assadi 1998; Posani 2009).

Hence, India’s farming costs continue to lag behind over the present low-cost producers. There is a growing view that most smallholders do not have a viable future, and agricultural development should focus on larger, commercially oriented farms that can be successfully integrated with technological breakthroughs and linked with emerging markets. The scale of operation is a significant factor in reducing costs as shown in Australian sugarcane farming system studies (Hanlon, 1996; Wegener, 2000). Further, greater integration of harvesting and transport operations would remove inefficiencies and better utilisation of capital leading to substantial gains for global competition. However, India provides a different picture of inverse relationships or lack of relationship in farm size and productivity (Sen, 1964; Dipak, 1965; Ashok, 1985; Mahesh, 2000).

Despite different farm size and technologies, in India small farm holdings have advantages that enable them to dominate. Small farms have lower labour-related transaction costs and more family workers per hectare, each motivated to work and supervise hired workers. Hence, small farms have an advantage in early stages of developing countries through low capital for unskilled workers. These advantages are slowly disappearing in India because of economic growth and labour scarcity through migration of workers to towns and non-farm jobs. Labour cost of cane cultivation has been increasing over the last few years.

Sugarcane being a highly labour-intensive crop, farmers divert to less labour-intensive crops, evident from the recent decrease in the area growing sugarcane. The only available alternative is to mechanise the farming operations. With millions of small and marginal land holdings, large-scale mechanisation poses many challenges compared to countries such as Brazil, Australia, Africa and Latin America where farm sizes are large. Large farms have lower capital and land-related transaction costs, allowing owners to more readily finance equipment that they can use over many hectares. Further efficiency, adaptability and manoeuvrability of these large machines in small farmer holdings are still under question.

With increasing wealth and the IT revolution in India, many farmers are sending their children for education in cities—then take up jobs in cities or abroad. The wealthy, salaried middle class with decreasing loyalties to agriculture and the village still owns a large part of the rural land (Lindberg, 1995; Gupta, 2005). In rural societies, the identities of villager and farmer and how they relate to village are changing. Managing, sustaining and improving productivity of these absentee landlords offers new opportunities and challenges for innovation. This requires a new pragmatic approach with deep insight to customer’s minds to reduce the drudgery associated with farming and offer benefits to customers.

**Environmental issues**

Sugarcane cropping systems that use intensive land, water and other inputs continue to raise concerns about environmental issues and sustainability of farming (WWF, 2003). Globally, irrigated agriculture accounts for almost 70% of water withdrawn for human use. Ground water withdrawals exceeding natural recharge rates of aquifers are leading to the lowering of water tables,
salinisation and land subsidence in many parts of the world. There is not enough additional water resources that can be diverted for increased sugarcane production. In countries such as India, the current water development and management system is not sustainable. India has a highly seasonal pattern of rainfall with 50% of precipitation falling in just 15 days and over 90% of river flows acquired in just 4 months. India’s dams can store only 200 cubic metres of water per person constituting 30 days of rainfall compared to 900 days in the major river basins (World Bank, 2005; IPCC, 2008).

Over the last two decades, 84% of the total addition to net irrigated area came from exploitation of ground water and only 16% come from canals. By 2020, India will need about 29% more water for agriculture, whereas water availability for agriculture is likely to be reduced by 12%.

In 2007, the Intergovernmental Panel on Climate Change (IPCC, 2007) confirmed that climate change is accelerating and, if the present trend continues, average global temperature will rise by 6°C in the long term. A compounding fact is that there is likely to be rapid de-glaciations in the Himalayas, resulting in a substantial impact on the river flows in India. Further, an Indian model of climate change suggests a decrease in the number of rainy days and an increase in extreme precipitation.

This means that the water requirements of sugarcane need to be minimised through finding ways to improve productivity of the crop per drop of water. Irrigation technologies such as furrow, border and flood irrigation need to be replaced by sprinkler and drip irrigation to increase water use efficiency.

**Technological changes**

Sugarcane is among the plant kingdom’s most efficient converter of sunlight into chemical energy that is stored in sugars, fibre and straw. These three products can yield 7192.92 MJ from one tonne of cane–equivalent to 1.2 barrels of oil (Oliverio and Riberio, 2006). Over the last 30 years, Brazil has developed a successful ethanol industry.

Presently, 37 countries mandate for blending ethanol as a fuel component, either directly or blending with gasoline or fuel. Another important aspect of the sugarcane biomass source is the significant generation of electricity using bagasse, which reduces carbon dioxide emissions.

With integration of biotechnological and bioprocess engineering, the sugarcane biomass has been tailored to produce a wide range of products similar to petroleum refiners, the so-called ‘Carbohydrate Economy’ (Allen et al., 1997; Rogers et al., 2001; Edye et al., 2007; Gravitis, 2007).

At the farm level, improved productivity per unit area is critical. In response to concerns about the sustainability of ‘Green Revolution’ technologies and their ability to manage the environmental interface, many are advocating agro-ecological and sustainable agriculture approaches, based on ecological principles of farming (REAP, 2003; Suttivan, 2003). By contrast, advocates of biotechnology argue that biotechnology can help to overcome limitations and offer major yield benefits.

Although these two approaches represent themselves in opposition to one another, both approaches have been integrated successfully in small farms in India with respect to Bt-cotton. These ecological methods include technologies for land preparation, water conservation, soil health and balanced nutrition, farm management, integrated pest and disease management in a sustainable way.

Conventional sugarcane breeding continues to be the major source of varieties. Complexities of breeding, a narrow source of germplasm and diverse requirements of industry resulted in recent biotechnological interventions in the sugarcane genome (Fitzgerald and Bonnett, 2007). However, their commercial applications have so far been limited to field trials. Advances in biotechnological
manipulations, integrated with ecological principles, will play a significant role in future sugarcane productivity improvements.

**Sugar: Indian scenario**

The sugar industry in India is the second largest agro-industry with more than 516 sugar mills operating in 18 states, and it plays a significant role in socio-economic development in rural areas (KPMG, 2007 and MoCFA, 2007). About 249 factories are in the co-operative sector and the balance is in the private or public sector. About 50 million sugarcane farmers and a large number of agricultural labourers are involved in sugarcane cultivation and ancillary activities, constituting 12% of the rural population. In addition, the industry provides employment to about 2 million skilled/semi-skilled workers mostly from rural areas.

Sugarcane growing areas of India may be broadly classified into three regions based on agro-climatic conditions, yield of cane and sugar content (Table 1).

<table>
<thead>
<tr>
<th>Region</th>
<th>State</th>
<th>Average yield (t/ha)</th>
<th>Average sugar recovery (%)</th>
<th>Average crushing days</th>
<th>Temperature Min (°C)</th>
<th>Temperature Max (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub Tropical-North</td>
<td>Bihar</td>
<td>42.91</td>
<td>9.13</td>
<td>93.00</td>
<td>7.7</td>
<td>41.5</td>
</tr>
<tr>
<td></td>
<td>Uttar Pradesh</td>
<td>57.57</td>
<td>9.92</td>
<td>134.42</td>
<td>3.6</td>
<td>42.6</td>
</tr>
<tr>
<td></td>
<td>Uttaranchal</td>
<td>57.95</td>
<td>9.54</td>
<td>131.00</td>
<td>2.1</td>
<td>42.1</td>
</tr>
<tr>
<td></td>
<td>Punjab</td>
<td>60.21</td>
<td>9.60</td>
<td>107.85</td>
<td>4.6</td>
<td>43.6</td>
</tr>
<tr>
<td></td>
<td>Haryana</td>
<td>60.54</td>
<td>10.00</td>
<td>136.28</td>
<td>4.1</td>
<td>43.3</td>
</tr>
<tr>
<td>Sub Tropical-Central</td>
<td>Gujarat</td>
<td>72.08</td>
<td>10.70</td>
<td>154.14</td>
<td>11.1</td>
<td>40.9</td>
</tr>
<tr>
<td></td>
<td>Maharashtra</td>
<td>72.77</td>
<td>11.46</td>
<td>116.71</td>
<td>10.9</td>
<td>42.8</td>
</tr>
<tr>
<td></td>
<td>Karnataka</td>
<td>83.74</td>
<td>10.56</td>
<td>141.85</td>
<td>14.4</td>
<td>41.5</td>
</tr>
<tr>
<td>Tropical-South</td>
<td>Orissa</td>
<td>59.01</td>
<td>9.33</td>
<td>72.42</td>
<td>11.5</td>
<td>41.2</td>
</tr>
<tr>
<td></td>
<td>Andhra Pradesh</td>
<td>76.64</td>
<td>10.16</td>
<td>123.85</td>
<td>13.6</td>
<td>41.0</td>
</tr>
<tr>
<td></td>
<td>Tamil Nadu</td>
<td>100.25</td>
<td>9.59</td>
<td>185.85</td>
<td>18.5</td>
<td>37.5</td>
</tr>
</tbody>
</table>

Table 1—Classification of sugarcane regions of India.

Source: Sugar data from Cooperative Sugar Journal, published by Indian Sugar Mills Association
Temperature data from [www.indiawaterportal.org](http://www.indiawaterportal.org)
Values are average of 2001–02 to 2006–07

Sugarcane supply to mill is dependent on the cane production from a large number of small farmers within a 15–20 km radius (average holding less than one hectare). Crop cycle (plant and ratoon) is limited to two or three years because of extreme climatic conditions, compared to six to seven year cycles in other countries. The value chain of the sugar industry has significant regional variations in its profitability to farmers and millers (KPMG, 2007; ISMA, 2009). In India, the sugar industry is beginning to diversify to an integrated complex with co-generation of power and alcohol for industrial and fuel uses.

Sugar is a controlled commodity in India under the Essential Commodities Act of 1955 and is regulated across the value chain. The heavy regulations in the sector artificially impact on demand-supply forces, resulting in market imbalance. Due to a realisation of these problems, since 1993 the regulations have been progressively eased out. However, central and state governments still have control over the sugar value chain, through mandatory and state advisory cane price (SMP and SAP), mill capacity expansion, geographical area of operation, by-product utilisation and movements, levy and sugar release mechanisms and exports and various forms of taxes at central and state level.

**Cyclical sugarcane and sugar production**

Since independence, the land area under cane cultivation, cane production, productivity and sugar production has increased dramatically (Figures 1 and 2).
Fig. 1—Cane area and sugarcane production, India.

Fig. 2—Sugar production and consumption—growing trends.
Irrespective of increased growth in area and productivity, production of sugarcane and sugar fluctuate considerably from year to year in India (Figure 1). This volatility is influenced by natural and man-made factors (KPMG, 2007; Gopinathan and Sudakaran, 2009).

Natural factors include distribution of rainfall, climatic conditions of flood and droughts, pests and diseases. Man-made factors are primarily government policies regarding sugarcane price, release mechanism, taxes and export and import controls.

In the past, these cycles arose every 4 to 5 years (Figure 3). In recent years, these deficit/surplus gaps are becoming wider irrespective of stock positions and various control regimes. India started its biofuel initiative in 2003.

This initiative differs from the rest of the world in its choice of raw material for biofuel production: molasses for bio-ethanol (Gopinathan and Sudakaran, 2009). Cyclicality of sugar, molasses and ethanol production and restrictive policies, availability of molasses, and fluctuating price hampered the fuel ethanol program.

**Strategic options**

Various authors have projected the demand supply requirements of sugar for the next decade (Table 2). Most projected a wide gap between demand and supply. It is evident from the factors that increased production can be brought only through productivity improvements per unit area.

**Table 2**—Projected demand supply—sugar based—food, fuel and power.

<table>
<thead>
<tr>
<th>Reports</th>
<th>Year</th>
<th>Demand millions</th>
<th>Supply millions</th>
<th>Gap millions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surabhi, M, 2008</td>
<td>2021</td>
<td>55 tonnes</td>
<td>26.6 tonnes</td>
<td>-28.4 tonnes</td>
</tr>
<tr>
<td>KPMG, 2007</td>
<td>2017</td>
<td>28.5 tonnes</td>
<td>25.0 tonnes</td>
<td>-3.5 tonnes</td>
</tr>
<tr>
<td>Vision 2025</td>
<td>2025</td>
<td>44.1 tonnes</td>
<td>32.3 tonnes</td>
<td>-11.9 tonnes</td>
</tr>
<tr>
<td>SBA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alcohol–Ethanol E10</td>
<td></td>
<td>3961 litres</td>
<td>3013 litres</td>
<td>-948 litres</td>
</tr>
<tr>
<td>Co–generation potential</td>
<td></td>
<td>9700MW of power</td>
<td>48 million carbon credit</td>
<td></td>
</tr>
</tbody>
</table>
The vision 2025 document of the Sugarcane Breeding Institute (ICAR, 2007) envisages at least the average yield of the sugarcane to be increased (105 tonnes per hectare from the present 67.5) to meet the sugarcane production of 450 million tonnes from 4.3 million hectares in 2020 (Table 2). This is going to be a challenging task.

Yield levels in cane and sugar has plateaued for the last 10 years (Figures 4 and 5) and shows wide variability between three agro-climatic regions and cyclicality year after year (Figure 6).

![Fig. 4—Cane area shift and yield gaps year after year.](image)

![Fig. 5—Cane yield and recovery, Plateau Trend.](image)
Even within the 15–20 km radius of a supply area representing 20 000 farmers, yield levels can range from 1–10 to 100 tonnes per hectare (Figure 7). Such wide variations within the farm and among farms and year after year has been attributed to complex agro-ecological conditions, access and adoption of technologies, cash and credit availability, timing of application of inputs, management of biotic and abiotic stresses, availability of power and labour, and willingness to manage risks. Heavy investments in inputs, infrastructure, and technology added with credit and weather risks and declining profitability can lead to pervasive indebtedness of small farmers. Technologies themselves are not sufficient to bring sustainability and profitability to farming in these situations.
There is an urgent need to evolve strategies and feasible alternatives for creating a viable future for the small farmers. Scientists need to re-orient and adapt to understand the management issues of farming, considering the bio-physical and socio-economic components. There is a need to consider the farmer beyond the passive receiver of technologies and information to a ‘partner’ in the entire value-chain.

Various interlocking arrangements, such as contract, network and leased farming, can create highly integrated backward and forward linkages converting small farmers as entrepreneurs in their own backyards. There is a need for a concerted effort by governments, millers, research institutions and non-governmental organisations to create a more equitable, economic environment for these small farmers to compete in a global context.

This includes targeted customer-oriented agricultural research and extension at local, state and national level, tenure security, efficient land management, assured market-linked competitive price, micro-credit facilities, risk management policies and technology/knowledge access with hassle-free farming.

In addition to this, government needs to continue investment with increased allocations in basic infrastructure such as roads, irrigation, communication, health, and strategic research and extension with long-term objectives.

**Parry way: a strategic initiative**

This calls for a different approach to the dissemination of agricultural research technology for sugarcane production in India by the millers. The conventional pipeline approach to agricultural research and extension has its serious limitations to meet the broad-based sustainable agriculture with complex demands of environmental, economic and diverse aspirational level of farmers.

An innovative integrated approach practised by Parry (*Parry way*) from cane registration to delivering payment on-line to the farmer at his doorstep using research, information technology, extension, development of Farm Process, out-sourcing (FPO) at village level in co-operation with financial institutions, and net working with National and State Research Institutions and Government establishments is depicted as a conceptual framework in Figure 8.

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**Fig. 8—Farmer relationship: conceptual framework—Parry Way.**
The approach emphasises that innovation is a systemic process and can emerge from any source, complex interactions and the knowledge sources throughout the value chain—farmer to consumer. The conceptual framework envisages a millers’ partnership with farmers in an interdependent way to ensure their aspirations are met through mutual dialogue and service rendered to facilitate hassle-free farming.

On registration of his land for cane, the grower is offered by the miller credit or advance and infrastructure loan either directly or through banks to facilitate easy cash flow.

Extension/Operation staff provide crop advice, farming calendars, soil analysis reports, fertiliser recommendations and suitable varieties. Farm Process Outsource (FPO) centres were developed within the village by selecting entrepreneur farmers and providing technical and financial support.

These FPO centres at village level deliver services at farmers’ door-steps by a mobile call or a request from land preparation to harvesting including the supply of inputs. On successful completion of each activity, millers make the payments to FPO and deduct the same from the farmer’s cane proceeds, enabling cash flow of the FPO.

Agricultural extension staff reduce the risk of farming operations through insurance, survey, monitoring and controlling crops from pests and diseases. Operation staff organise harvesting, transport of cane to factory and payments on time (within 14 days). In-house research staff continue to develop Parry varieties and technologies and also out-source suitable varieties and technologies from National or State institutions.

Traditional on-farm demonstrations, print media, and TV, combined with modern on-line kiosks, are used for communication and information sharing. Traditional class rooms, on farm training and feedback sessions, are an integral part of farmer training offered throughout the year. Information and communication technologies, integrated with geographic information, financial and cane management systems offer reliable and crop-specific information and knowledge flow on-line, accessible through kiosks, internet or mobile phones (Figure 9).
Such information flow throughout the value chain enables traceability of agriculture even to small farms and also facilitates sustainability certification standards.

Open communications and access to information continue to build trust and relationships among the partners and create new avenues of opportunities for extracting value throughout the chain on a sustainable and profitable way for all stakeholders.

Beyond the convenience of farming, working together through an integrated professional culture, the farmer and FPO develop a sense of pride and ownership within himself and in his village.

Such relationships and respect can play a reversal role in rural-to-urban migration in the long term by attracting and retaining youth in farming and thus making farming intellectually stimulating, financially rewarding and a respectable profession.

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STRATEGIES DE TRANSFERT EN RECHERCHE ET TECHNOLOGIE POUR LA PROCHAINE DÉCENNIE–UN EXAMPLE INDIEN

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MOTS-CLÉS: Canne à Sucre, Recherche, Innovation,
Transfert de Technologie, Vision de Parry.

Résumé
LA GLOBALISATION est en train de conduire à des réformes radicales externes et internes sans précédent dans les industries sucrières à travers le monde. Ajouté à cela, 5 forces émergentes, qui montent en puissance, vont redessiner la production de canne à sucre et l’industrie sucrière dans le futur, avec des implications extraordinaires sur le plan démographique, économique, sociopolitique, environnemental et technologique. Cet article dresse tout d’abord un tableau de la croissance et du statut de l’industrie sucrière et l’impact des forces émergentes sur le remodelage des systèmes de production agricoles. La complexité et la diversité émergente des exploitations agricoles requièrent la mise en place d’un modèle de recherche et de transfert de technologie nouveau et plus complexe. La consolidation des meilleurs systèmes pour l’exploitation, l’identification de la diffusion optimale des technologies et des problèmes d’adoption, ainsi que l’introduction de nouvelles technologies et pratiques innovantes dans la chaîne agricole va continuer de jouer un rôle primordial dans l’amélioration de la productivité. Les changements démographiques, le statut socioéconomique des planteurs et les prix relatifs à la compétitivité des cultures vont demander aux compagnies sucrières de fournir, en plus d’un prix compétitif de la canne, la livraison de divers services aux planteurs pour assurer un approvisionnement durable des cannes aux usines. L’introduction de nouveaux standards pour la durabilité et le besoin de certification pour les consommateurs conduira les compagnies sucrières à intégrer l’ensemble de la chaîne de valeur du planteur au consommateur au travers de divers formes de coopération, de relations et de partenariats. Ces réalités émergentes vont débloquer des potentiels inexploités et opportunités inutilisées à travers la chaîne de valeur pour créer une nouvelle architecture de recherche et de transfert de technologie et un paysage compétitif pour l’industrie sucrière en Inde.
ESTRATEGIAS PARA LA TRANSFERENCIA DE INVESTIGACIÓN Y TECNOLOGÍA PARA LA PRÓXIMA DÉCADA–UN EJEMPLO DE LA INDIA

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PALABRAS CLAVE: Caña de Azúcar, la Investigación, la Innovación, Transferencia de Tecnología, Parry Vision.

Resumen
LA GLOBALIZACIÓN está impulsando reformas internas y externas radicales y sin precedentes en las industrias de azúcar alrededor del mundo. Además de esto, cinco fuerzas principales emergentes o intensas, con grandes implicaciones extraordinarias - demográficas, económicas, sociopolíticas, ambientales y tecnológicas- moldearán el cultivo de caña de azúcar y la industria azucarera en el futuro. En primer lugar, este documento aborda el crecimiento y el estado de la industria azucarera y el impacto de estas fuerzas emergentes en el moldeamiento del futuro agrícola de la caña de azúcar. Complejidades y diversidades emergentes en la estructura y el proceso de explotación agrícola exigen un modelo nuevo y más complejo de investigación y transferencia de tecnología. La consolidación de las mejores tecnologías para la explotación máxima, la identificación de las lagunas de difusión y adopción de tecnología, y la introducción de nuevas tecnologías y prácticas innovadoras a lo largo de toda la cadena de agricultura van a seguir desempeñando un papel fundamental en la mejora de productividad de la caña de azúcar. Los cambios demográficos, el estado socioeconómico de los agricultores, y los precios de los cultivos competidores exigirán a las empresas de azúcar ofrecer, además de precios competitivos de caña, entrega específica de diversos servicios a los agricultores para asegurar un suministro sostenible de la caña. Introducción de nuevos estándares de sostenibilidad y la necesidad de certificación por parte de los consumidores conducirá a las empresas de azúcar a integrar la cadena de todo valor desde el agricultor hasta el consumidor, mediante diversas formas de cooperación, relación y asociación. Estas realidades emergentes abrirán potenciales sin explotar y oportunidades sin utilizar a lo largo de la cadena de valor para crear una nueva arquitectura de transferencia de investigación y tecnología y un panorama competitivo para la industria del azúcar en la India.
SUGARCANE RESEARCH AND TECHNOLOGY TRANSFER—STRATEGIES FOR THE NEXT DECADE

By

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KEYWORDS: Research Challenges, Multidisciplinary Research, Sustainability.

Abstract

AGRONOMIC challenges required for the decades ahead will focus on (1) research and technology transfer based on multidisciplinary approaches; (2) a transition from production-oriented models to consumer-driven systems; and (3) developments that promote sustainability and concerns for environmental issues. A multidisciplinary approach ensures that scientists, growers and factory engineers are aware of the contributions of other disciplines, rather than isolated, individual efforts. This requires not a narrowly focused ‘specialist’, but rather someone with a ‘special’ interest in various disciplines, whose wide vision could make integrated contributions to developing a true Renaissance in sugar industries. The transition to a consumer-driven model requires the identification of new priorities. Technologies for sugar production will remain a priority, but greater emphasis must be directed towards technologies for using sugarcane for energy production and for value-added products. In the case of energy production, the use of sugarcane has been possible because of the availability of proven technologies, interest from investors, government regulation and consumer demand. For value-added products, the challenge for scientists lies not just in concrete research outputs, as has been the case for sugar production. Their skills for knowledge management and the vision to transfer their achievements, open new markets and generate interest in funding new research must be strengthened. Sustainability and environmental protection will continue playing a role in future research, both in the field and in factory processes. Climate change is on the agenda of challenges that agronomists and their allied specialists must address in the design and management of future production systems. The prospective use of sugarcane as a source of bioenergy to reduce carbon dioxide emissions to the atmosphere offers an opportunity for scientists, investors and consumers to work together on sustainability and environmental protection. Research achievements and projections in the sugar industry worldwide, reported in the literature as well as by the Colombian sugar industry, are used to illustrate these strategies.

Introduction

Technology development and the strategies for responding to the consumers of sugarcane by-products in the next decade will depend on the clear identification of their consumption requirements and trends.

History shows that countries or sectors that invest greater resources in Research and Development (R&D) achieve greater socioeconomic development while responding to their consumers (OECD, 2008).

The technological advances of the last century have generated benefits for mankind, which have also been incorporated in the technology developments of our sugar agro-industries and can be linked to what is called the innovation revolution (Hockfield, 2009).
This revolution is based on the convergence of several areas of knowledge that we should maintain and strengthen. The first of these, which took man to the moon, developed communications, improved agricultural production and sustained economic development during the decade of the 1950s that was based on the convergence of engineering and the physical sciences. The second took place in the 1980s with the information explosion generated by genomics and proteomics, which accelerated innovation in the life sciences. These two supported the third, which integrates life sciences, engineering and physical sciences. Accelerating these innovations will require changes in education, sources of financing and interaction among those who have the knowledge and between them and the users of the resulting technological products.

The technological challenges depend not only on the resources and infrastructure that are available. The new technological advances that will benefit our agro-industries will depend ever more on (a) R&D and innovation based on multidisciplinary teams, teamwork and alliances with other institutions; (b) the transition from production-oriented to consumer-defined work models; and (c) developments that promote sustainability and greater relevance of environmental issues.

**Multidisciplinarity, teamwork and alliances**

Research based on multidisciplinarity, teamwork and alliances highlights the importance of agro-industrial researchers and professionals being aware of the contribution of other disciplines and of the knowledge from their settings in a globalised world. This contrasts with continuing to face the challenges and solutions required in an isolated fashion.

In the former case, a broader vision of the environmental settings identifies the reality of technological requirements and the opportunities for new developments. There are three principal products that are derived from sugarcane that are in demand by consumers and on which today’s R&D is centred: sugar, ethanol and co-generation of electricity. Of the 1.4 billion tonnes of sugarcane produced today, approximately 75% is destined for sucrose and 25% for ethanol. The co-generation of electricity and the use of products with added value are minimal but have great potential (ISO, 2008a).

A knowledge of consumer demand and interests is decisive for defining future research. If the target is to improve the efficiency of sugar production, technology developments should not be indifferent to population growth and consumption. Income (ISO, 2004) and socio-political factors also influence future consumption. In absolute terms, large populations tend to be associated with high levels of sugar consumption. It is not surprising that the five countries with the greatest growth in consumption in absolute terms are among the ten largest in population.

Future expectations of research funders will be for technological advances that contribute to a greater demand for sugar and its by-products and, consequently, generate greater productivity, income and promote sustainability. Greater income can contribute to a greater demand for sugar and its by-products and, consequently, create challenges for new technology developments. In a global economy in crisis, we are part of the solution; thus knowledge of the environmental setting is fundamental.

Technological advances and their impact on productivity in the sugar industries are evident in the last 30 years. Advances in productivity, a function of technology development (Cox et al., 2005; Edme et al., 2005; Cenicana, 2008; Davis, 2007) highlight the role of R&D for responding to the 2% yearly increase in the consumption of sugar, which today is 160 million tonnes. Despite the progress made in productivity, improvements have not plateaued, so there remain opportunities for improvement via multidisciplinary groups and alliances.

Increased productivity has contributed to reducing the use of the land without affecting food security through expanding the planting of cane in areas occupied by other food crops. This has been the experience of the sugar agro-industry in Colombia, where thanks to the technology developments in the last 30 years, the productivity in sugar has doubled without having to expand the crop to other farming areas (Asocana, 2007).
Sugar industries worldwide use only one-third of the plant’s biomass to produce sugar, so R&D has focused on this aspect. With the potential to use the biomass as a source of energy, either for ethanol or co-generation of electricity (Leal, 2007), demands for new technology offers an opportunity for research. This means the validation and adoption of available technologies, research at the level of cane production in the field and in industrial processes, changes in attitude toward working in multidisciplinary teams, knowledge of the environmental setting, and response to the challenge of using the biomass in a sustainable production system. The updating and acquisition of new knowledge should be permanent, but we should also progress as individuals. Researchers and the organisations need to do their part in order to make full use of the strengths of the human talent and facilitate the improvement of their capacities.

Over the next ten years, the challenges will be greater given the technological advances and impacts reached thus far. This means greater knowledge and integration of other disciplines; and, although there may be a need for greater funding, integration can lead to better rationalisation in the use of the resources and capacities.

What the users of the technology expect will be based not only on the number of products but also on the benefits that they generate (Mervis, 2005). This will be accomplished by integration, teamwork and alliances. Agronomists and professionals linked to cane production will continue to play an important role in facing these challenges, but they will not necessarily be the only actors in the future scenario of agricultural research (Miller, 2008). After the ‘Green Revolution’ era, centred on commodities and research in organisations, the ‘Evergreen Revolution’ has followed, centred on the integrated management of natural resources and participatory research (Swaminathan, 2006). This should be accompanied by a continuous technology transfer and prompt adoption of innovative technologies in order to exploit them at the right moment and not when they are obsolete.

Multidisciplinarity implies interaction. Interaction of researchers with the users of their products should be emphasised in order to provide the scientific foundations for the new technologies and about the concerns that end users may have. The assumption that the user of the technology understands the scientific bases of the developments is not sufficient – the problem is not one of scientific comprehension but of satisfying their needs and concerns (Leshner, 2007).

On the other hand, there is a tendency in the minds of those who need the technology – cane producers, managers and funders – to minimise the range of actions that researchers can have. In some cases, the users feel intimidated by the idea of working with researchers. The best way to change such an attitude is through permanent interaction with them in the environment in which the work is being done (Alberts, 2009).

The culture of teamwork is now beginning to be visible, and it should become stronger in the future. A recent study of publications in the last five decades shows that work teams (reflected in the number of authors) significantly surpasses individual authors in the majority of scientific fields (Wuchty et al., 2007).

The benefits of alliances are also evident in the sugar industry worldwide. One of the best examples is the International Consortium for Sugarcane Biotechnology (ICSB), which integrates 14 countries and 19 institutions in the search for genetic and molecular knowledge of sugarcane and the search for genes of agronomic interest.

All participants contribute to the definition of priorities and finance the research. This has generated knowledge that contributes to improvement and technology development that would not have been possible working in isolation (Moore, 2005).

Internally, at the level of the countries, alliances are being made; and the actors related to R&D are being integrated, such as has occurred in Australia (Maldonado and Troedson, 2009), South Africa (SASRI, 2007), and Colombia (Amaya, 2008), among others. We need to be open to joint developments for generating knowledge, technology and greater welfare in our agro-industries.
The foregoing gives an idea of the profile of the specialist required in the coming decade. This requires not a narrowly focused ‘specialist,’ but rather someone with a ‘special’ interest in several disciplines, whose wide vision could lead scientists to make significant contributions to developing a true Renaissance in our industries.

**From production-oriented models to consumer-driven systems**

The transition from production-oriented work models toward consumer-driven work models requires going beyond the indicators of productivity. Added value, cost reduction, quality raw materials, compliance and interest in the market and consumers’ proposals need to be kept in mind in the new production model.

The production of the sugar already has technological support and experience in R&D. In the future, the refining of the current technology and incorporation of others in the development process are needed.

Cane producers will face an increased demand from the cane processors for cane with higher sucrose content and less extraneous matter. For the sugar producers, greater value can come from supplying the type of product that the consumer wants. This will range from different forms of sugar to nutraceutical products with information on their effect on health and clarity as to their origin with respect to the production system or to whether they were obtained through conventional genetic improvement or genetically modified varieties. A well-informed consumer demands better knowledge of the product.

For more than two centuries, cane has been fundamentally used to produce sugar. In the case of the production of ethanol, the transition has been relatively smooth because the same varieties and the system for producing cane in the field are used, and there were well tested industrial production technologies available in the market. Moreover, the countries that have led the production of ethanol have also had a supporting platform of government regulations, and there has been an ever-growing interest in clean energy on the part of the consumers.

Today, the use of sugarcane to produce value-added products other than ethanol faces a different scene. The challenge for R&D and innovation is even greater given that their impact will depend not only on the technology **per se**, but also on a greater capacity for managing knowledge, a vision for innovation, transfer and marketing of results and technologies, and different forms and sources of financing. The benefits derived from other products with added value are expected to have an economic impact and sustainability that will motivate new R&D and open doors for new financing.

Technology development in the world’s leading sugar industries has been financed to a great extent by the sugar industries themselves, complemented by support from the respective governments. The tendency towards networking, and the complement of external financing have the potential for generating products or patents of greater value in shorter time and with lower costs, incorporating the knowledge of researchers from different organisations.

The availability of information about external funding for the sugar industries is scarce. However, there is a growing trend in this direction, given the global financial crisis. External funding requires a change of paradigms. It is imperative that researchers be aware that, in addition to the economic support from our industries, we also have a ‘capital’ of great value. This is knowledge that we should strengthen and exploit in order to generate greater value, and be supported by an external finance.

In this sense, researchers should be more proactive and eliminate some of their rationalisations that still prevail; e.g. lack of time, ignorance in how to proceed, belief that someone else should do it, believe that is something too big and lacking aid, among others (Wells and Farnham, 2006). Such attitudes must be eliminated in future researchers if they are to attract funding with competitive proposals and based on their merits.
Sustainability and concerns for environmental issues

Developments that promote sustainability have become current concerns, given that, in addition to the investors’ expectations, there is the consumers’ interest of preserving natural resources and conserving the environment. The potential for reducing carbon dioxide emissions to the atmosphere through the use of renewable energy sources such as sugarcane makes this crop an ideal option. A global vision, multidisciplinarity and strategic alliances can generate a better future for the sugar industries that face these challenges.

Sustainability, understood as satisfying the needs of the current generation without compromising the needs of the future generations (IPCC, 2007), refers to the need to take into account the economic, social and environmental benefits in any production system. Unfortunately, political interests have also arisen around this topic; thus, it is imperative that researchers be informed as to what is going on in their settings in order to give an objective response based on research or to incorporate those concerns in future research.

Sugar industries around the world have been incorporating sustainability in their technology developments related to the environmental issues. If we start with the production in the field, the raw material is the genetically improved varieties. In the majority of cases, new varieties have generated greater production with the same level of natural resources (soil and water) and inputs less than those used previously. This also contributes to the social component, freeing-up arable land and improving the efficient use of the water. In the Colombian sugar industry, improvements in technology for water management (Torres et al., 1996, 2004) and planting varieties that require less irrigation (Victoria et al., 2002) have reduced water consumption by approximately 50% without affecting production.

In the case of the cane varieties, the majority of those released are resistant to diseases and pests, which decreases the use of agrochemicals. In the control of some pests, the use of biological control is routine, which decreases the use of insecticides.

Today, field technology is targeted to specific conditions, defining the technologies, varieties and agronomic management practices in accordance with climatic zones and the cane producers (Carbonell et al., 2001; Isaacs et al., 2007). This site-specific agriculture approach has generated up to 30% increases in production in some zones of the Colombian sugarcane industry (Isaacs et al., 2007; Viveros et al., 2009). The management of the crop in the field with specific technologies and the search for environmentally friendly products will be of relevance to the final acceptance by consumers. Therefore, this should be a priority in future research.

Climate change is a reality (IPCC, 2007); and, in order to adapt or mitigate the effects of this change, future actions should consider changes of scale. We have moved from a temporal scale of the climate that affects a crop cycle for short periods of time to consider the impact of the evolution of the climate over hundreds or thousands of years on agriculture and life today on the planet. We’ve also moved on the spatial scale, from metres or hectares to regions and the entire globe (Steiner and Hatfield, 2008). This reality leads us to define different strategies in the management of the inputs required for producing the crop and the industrial processes. That is another reason for working together.

A focus on climate change projects a more integrated vision for future R&D. There are platforms for analysing the impacts of climate change and the measures required for mitigating them in sugarcane (Nayamuth, 2005; Schulze, 2007; Park, 2008). The use of cane for biofuels contributes not only to reducing the dependence on fossil fuels, but also to reducing carbon dioxide emissions into the atmosphere.

The Brazilian experience and their success in the ethanol production system is today a reference point for industries that are moving to the production of biofuels. We should learn from this arduous path and the weaknesses they have to overcome in this development. That will help project the research that fills the information gaps for both science and for society.
Conclusions

R&D challenges facing the sugar industries in the next decade will depend on strategies that involve greater emphasis on changing the way of doing things more than on the development of the technology per se. Technological advances will be fundamental, but changes in our attitudes that promote multidisciplinarity, teamwork and alliances will underpin innovations of impact that will generate greater growth of our industries, consumer satisfaction and sustainability of the ecosystems where sugarcane is produced and processed. The renaissance that we expect to occur in the world’s sugar industries will depend on incorporating in our R&D the vision that prevailed in the era of Renaissance of a ‘Homo universalis’ with an open mentality and interest in the advances of other disciplines that will contribute to realise the potential of today’s capacities to address future challenges.

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LA RECHERCHE SUR LA CANNE À SUCRE ET LE TRANSFERT DE TECHNOLOGIE – STRATEGIES POUR LA PROCHAINE DECADE

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MOTS-CLÉS: Défis de la Recherche, Recherche Multidisciplinaire, la Durabilité.

Résumé

Les challenges agronomiques nécessaires pour les décades à venir seront centrées sur (1) la recherche et le transfert de technologie basés sur des approches multidisciplinaires; (2) une transition à partir de modèles de production orientés sur des systèmes pilotés par les consommateurs et (3) des développements qui promeut la durabilité et les préoccupations concernant les enjeux de l’environnement. Une approche multidisciplinaire permet aux scientifiques, planteurs et ingénieurs d’usine d’être informés des contributions des autres disciplines, plutôt que sur la base d’efforts individuels isolés. Il ne s’agit donc pas d’avoir un spécialiste à vision étroite, mais plutôt quelqu’un qui a un intérêt particulier dans plusieurs disciplines, et dont la vision permettrait d’intégrer les contributions pour développer une renaissance des industries sucrières. La transition vers un modèle piloté par la demande des consommateurs requiert l’identification de nouvelles priorités. Les technologies de la production de sucre vont rester prioritaires, mais une pression plus importante doit être mise sur les technologies utilisant la canne à sucre pour la production d’énergies et d’autres produits à valeur ajoutée. Dans le cas de la production énergétique, l’utilisation de la canne à sucre a été possible grâce à la disponibilité en technologies éprouvées, l’intérêt des investisseurs, la régulation du gouvernement et la demande du consommateur. Pour les produits à forte valeur ajoutée, le challenge pour les scientifiques, ne se situent pas uniquement au niveau des retombées de recherche comme cela a pu être le cas pour la production de sucre. Leur aptitude à appréhender la connaissance du management et leur vision pour le transferts des résultats, à ouvrir de nouveaux marchés et à générer de l’intérêt pour financer de nouvelles recherches doit être renforcer. La durabilité et la protection de l’environnement va continuer à jouer un rôle dans la recherche future que ce soit au champ et au niveau des processus technologiques dans les usines. Le changement climatique fait partie des challenges que les agronomes et leurs partenaires spécialisés doivent prendre en compte dans la conception et le management des systèmes de production du futur. L’utilisation prospective de la canne à sucre comme source d’énergie pour réduire les émissions de dioxyde de carbone dans l’atmosphère offre une opportunité pour les chercheurs, les investisseurs et les consommateurs de travailler ensemble sur la durabilité et la protection environnementale. Les avancées majeures de la recherche et les projections dans l’industrie sucrière à travers le monde répertoriés dans la littérature et au niveau de l’industrie sucrière colombienne, sont utilisés pour illustrer ces stratégies.
INVESTIGACIÓN Y TRANSFERENCIA DE TECNOLOGÍA DE LA CAÑA DE AZÚCAR- ESTRATEGIAS PARA LA PRÓXIMA DÉCADA

Por

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PALABRAS CLAVES: Desafíos de la Investigación, Investigación Multidisciplinaria, Sostenibilidad.

Resumen

Los desafíos agronómicos requeridos para las próximas décadas se centrarán en (1) la investigación y la transferencia de tecnología basada en enfoques multidisciplinarios, (2) una transición de modelos orientados a la producción a sistemas dirigidos por el consumidor, y (3) los desarrollos que promuevan la sostenibilidad y las preocupaciones en cuestiones medioambientales. Un enfoque multidisciplinario garantiza que los científicos, los cultivadores y los ingenieros de fábrica sean conscientes de las contribuciones de otras disciplinas, en lugar de esfuerzos aislados e individuales. Esto requiere no tener un enfoque en el restringido 'especialista', sino más bien a alguien con un interés 'especial' en diversas disciplinas, cuya visión amplia le daría la capacidad de hacer contribuciones integradas para el desarrollo del verdadero renacimiento en las industrias de azúcar. La transición a un modelo orientado al consumidor requiere la identificación de nuevas prioridades. Las tecnologías para la producción de azúcar seguirá siendo una prioridad, pero un mayor énfasis debe ser dirigido hacia las tecnologías para el uso de caña de azúcar en la producción de energía y productos de valor añadido. En el caso de la producción de energía, el uso de la caña de azúcar ha sido posible dado a la disponibilidad de tecnologías probadas, el interés de los inversionistas, regulación del gobierno y demanda del consumidor. Para los productos de valor agregado, el reto para los científicos consiste no sólo en los resultados concretos de investigación, como ha sido el caso para la producción de azúcar. Sus habilidades en gestión del conocimiento y su visión para transferir sus logros, abrir nuevos mercados y generar interés en financiar nuevas investigaciones deben ser fortalecidas. La sostenibilidad y la protección del medio ambiente seguirán desempeñando un papel en el futuro de la investigación, tanto en el campo como en los procesos de fábrica. El cambio climático está en la agenda de los desafíos que deben abordar los agrónomos y sus aliados especialistas en el diseño y administración de futuros sistemas de producción. El uso prospectivo de caña de azúcar como una fuente de bioenergía para reducir las emisiones de dióxido de carbono a la atmósfera ofrece una oportunidad para que los científicos, los inversores y consumidores trabajen juntos para la sostenibilidad y la protección del medio ambiente. Los resultados de investigación y las proyecciones de la industria del azúcar en todo el mundo, reportados en la literatura, así como por la industria del azúcar colombiana, se utilizan para ilustrar estas estrategias.
KEYWORDS: National Programs, Stakeholders, Matrix Management.

Abstract
Research is the cornerstone for maintaining healthy and sustainable agricultural industries. Systems for obtaining funding and managing and dispersing resources are as diverse as are there systems for culturing sugarcane. This paper presents a model of managing agricultural research programs at the Federal agency level. The Agricultural Research Service (ARS) is USDA’s principal in-house agricultural research agency and, as a Federal agency, it is tasked with conducting publicly-funded research for the benefit of the United States. ARS aims to generate relevant, significant, and timely scientific information for use by the Agency’s many stakeholders: agricultural producers, food processing industries, natural resource managers, universities, and non-profit research institutions. To ensure that these objectives can be achieved, ARS implemented the National Program cycle, a cycle of phases embodying a series of recurring activities. Customers and stakeholders are actively engaged in each phase of the process and their contributions are integral to the direction of research and its success. Input, Planning, Implementation, and Assessment — are the four sequential phases through which ARS research progresses, ensuring that it remains of the highest quality. The cycle ties these activities together in a recurring 5-year sequence to ensure an effective and efficient program and project management within ARS. These efforts are aimed at maintaining a sustainable sugarcane industry that is responsive to changing economics, production problems, and opportunities, and will require continued Federal, but also State, private, and international cooperation to be successful. The beneficiaries of a sustainable sugarcane industry will be the citizens of the U.S. who will enjoy abundant and affordable sugar and sugar-based products.

Introduction
The Agricultural Research Service (ARS) is USDA’s principal in-house agricultural research agency and, as a Federal agency of the United States, it is tasked with conducting publicly-funded research for the benefit of the United States. To meet this mission, ARS has developed a system for developing and managing the Agency’s research priorities that actively engage the private and public sectors in research planning and implementation.

ARS aims to generate relevant, significant, and timely scientific information for use by the Agency’s many stakeholders: agricultural producers, food processing industries, natural resource managers, universities, and non-profit research institutions. The larger body of USDA beneficiaries, customers, and stakeholders includes U.S. consumers, other Federal agencies such as the Food and Drug Administration, regulatory agencies such as USDA-Animal Plant Health Inspection Service (APHIS) and the Environmental Protection Agency (EPA), and international markets.

Management of the ARS national research programs is headquartered in Beltsville, Maryland—also home to the largest ARS research facility—which is in close proximity to USDA.
administrative headquarters in Washington, D.C. There are over 100 ARS research locations that serve crops, animals, natural resources, and food safety and quality throughout the United States, Puerto Rico, and the U.S. Virgin Islands, and four laboratories overseas.

Individual laboratories are led by research leaders, who oversee a number of related research projects, and who are responsible for ensuring the quality and performance of each project. Laboratories are grouped into eight geographical areas, each of which is under the direction of an area director. Sugarcane research is located at these primary sites: Canal Point and Miami, Florida; Houma and New Orleans, Louisiana; and Beltsville, Maryland.

The number of facilities in each area varies, as does the research focus, but all ARS scientists are tasked with addressing agricultural issues of regional and national significance. These issues are identified and selected through a national priority-setting process involving scientists, customers, stakeholders, and program officials.

National scientific direction is provided by the Office of National Programs, located in Beltsville. National Program Leaders (NPLs) are assigned to specific programs for leadership, based on their expertise and the research area of need.

Sugar crops, including sugarcane and sugarbeet, are assigned to one NPL as part of their national portfolio of crop responsibilities, and that person works with a team of NPLs to address the diversity of issues facing the national research program.

The annual fiscal budget for ARS is set by the U.S. Congress and is nominally similar each year. In 2009, the total ARS budget was US$1.14 billion. Every spring, the NPLs, area directors, budget staff, and the agency administrator decide on the budget requests to be made for the following fiscal year, including what research should be continued, what new research should be initiated, and what, if any, should be terminated. These decisions are based on administrative priorities, progress obtained from individual annual reports submitted for each project, and research needs identified through ongoing contacts with stakeholders and customers associated with each national program.

To plan, implement, coordinate, and account for its research, ARS uses a matrix management approach. The matrix is composed of vertical (‘line’/local) management organised by geographic Areas, and horizontal (‘programmatic’/national) management organised by research programs (Office of National Programs), functions (budgeting, information technology, technology transfer, security), and business processes (administrative and financial management). The administrator and the executive team of ARS provide leadership to the matrix management system in accordance with the ARS strategic vision and mission, national program action plans, and established operating policies.

**Background: National program organisation**

Senior leaders in ARS moved toward the present concept of national programs in 1993. ARS leaders realised that, to remain on the leading edge of agricultural research, the agency approach to interdisciplinary, nationally collaborative research had to be updated. With better national coordination of ARS’s considerable resources, the agency could more effectively focus on significant problems of high national priorities.

In 1998, Congress decided that ARS establish procedures to enhance its accountability, and mandated that all new proposed research projects be subjected to scientific peer reviews. The ARS Office of Scientific Quality Review (OSQR) was organised as a result of this act, and is described below under Phase II: Planning.

Over the next few years, ARS revamped the way it managed its research portfolio; the 1000-plus research projects were aligned into 21 national programs that encompass all research in the agency. These national programs are grouped into four program areas: (1) Nutrition, Food Safety, and Quality; (2) Animal Production and Protection; (3) Natural Resources and Sustainable
Agricultural Systems; and (4) Crop Production and Protection (where most of the sugarcane research is conducted) (Table 1). Each of the four program areas is managed by a Deputy Administrator.

Each National Program is led by a team of NPLs, selected based on their area of expertise to provide research direction on a national level. Currently, 25 NPLs are responsible for planning and developing research strategies to address critical issues affecting American agriculture.

Table 1—ARS national programs.

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<td>• Human Nutrition</td>
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<td>• Food Safety (animal and plant products)</td>
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<td>• Quality and Utilisation of Agricultural Products: (Projects for sugarcane include sugar chemistry and physiology for optimising field and factory utilisation)</td>
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<th>Animal Production and Protection</th>
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<th>Natural Resources and Sustainable Agricultural Systems</th>
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<th>Crop Production and Protection (All programs listed below, except Methyl Bromide Alternatives, have research projects assigned to sugarcane)</th>
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Implementation of the 5-Year National Program Cycle

The overarching objectives of the National Programs are relevance, quality, and impact, all important elements of accountability for ARS research.

Research must be relevant to the highest priority problems; the goals and outcomes of the research should significantly impact the problems; and the science must meet the highest standards of quality. To ensure that these objectives can be achieved, ARS implemented the National Program cycle; a cycle of phases embodying a series of recurring activities (Figure 1).

Customers and stakeholders are actively engaged in each phase of the process described below, and their contributions are integral to the direction of research and its success.
The descriptors on the inside of Figure 1, input, planning, implementation, and assessment, are the four sequential phases through which ARS research progresses, ensuring that it remains of the highest quality. The cycle ties these activities together in a recurring 5-year sequence to ensure effective and efficient program and project management within ARS.

**Phase I: Input**

Research in ARS derives its strength from its responsive nature to the needs of the U.S. public. At the National Program level, senior program leaders meet with customers, stakeholders, and partners; participate in Federal and USDA working groups and initiatives; and interact with Congress to build a strong understanding of national issues in agriculture and science. At the local level, senior managers also meet with customers, stakeholders, and partners, and participate in working groups to build a strong understanding of issues facing producers and industry. Each type of input is coordinated to produce a responsive program and project. This holds true for sugarcane research as well, as state and national stakeholders and scientists team up with the NPL to develop a regional and national program that addresses the most critical needs in breeding, genomics, germplasm preservation and distribution, pathology and entomology, agronomy, weed science, horticulture, remote sensing and monitoring, physiology, and sugar processing technologies.

Although input from these constituencies is ongoing, formally and informally, throughout the program cycle, the beginning of the cycle marks the consolidation of all input into a National Program Action Plan. The largest formal face-to-face input mechanism, the National Program Customer/Stakeholder workshop, immediately precedes the writing of that Action Plan. These meetings are designed to define specific researchable problems aimed at meeting high-priority needs within the agricultural community.

The workshops also provide an opportunity for ARS research scientists and program managers to interact and develop rapport with customers, stakeholders, partners, non-ARS scientists, and representatives from other agencies. For example, in the Crop Production and Protection Area, leaders from most, if not all, commodities work with our scientists and NPLs to determine the most critical needs of industry. In addition, input is obtained at numerous meetings and workshops during the year that is either commodity- or discipline-based.

Commodity representatives contribute greatly to the success of ARS research by providing in-kind support to relevant programs. For the ARS sugarcane programs in particular, Florida and Louisiana locations both have close collaborations with their respective industry and university researchers, growers, and producers. In 2007, as a response to requests from industry, a national
ARS Sugarcane Workshop was held for the first time in almost 25 years. Results from that 2-day event were captured in an Executive Summary with a vision and mission statement and primary research needs that can be viewed on the ARS Web site:

Phase II: Planning

Planning of ARS research is organised at two levels: National Program and individual project planning. National program planning begins at Headquarters with the development of the Action Plan. This plan is based on the vision and mission of ARS that encompass the broad goals of the Agency and on feedback from the Customer/Stakeholder workshop to define (1) problems to be addressed, (2) actions ARS will take to achieve the mission and goals of the National Program, (3) expected targets or outcomes of the research, and (4) locations that will be responsible for carrying out the work. As such, Action Plans provide guidance for project development, but also for facilitating project review and assessment of the National Programs. Scientists who contribute to the National Program are engaged in the process and often assist in the writing and formulation of the Action Plan.

Subsequently, scientists and line managers participate in planning individual research projects. Using research objectives identified in dialogue between researchers and the National Program team, a Project Plan is developed that addresses — either with basic, applied, or developmental science—the primary research objective(s). A robust Project Plan outlines research approaches, defines interactions among team members, enhances scientist productivity and impact, and creates opportunities for working with collaborators.

Once developed, the 5-year project plan is submitted for external peer review under direction of the ARS Office of Scientific Quality Review (OSQR), which develops a panel of highly regarded university and industry researchers in related fields. The ARS NPLs select the panel chair only, who in turn selects the panel members. The panel is asked to evaluate and rate the scientific quality, methodology, and outcomes in the proposed project plan based on the direction outlined in the Action Plan. As part of the review, the panel can suggest changes in the Project Plan to improve focus or identify other research considerations that also should be addressed. Plans that do not receive passing scores are asked to revise their plans based on the panel’s comments and to resubmit for a second review by the panel. Once plans are passed by the panel, a new 5-year project is implemented.

Phase III: Implementation of the research plan

This phase covers a wide range of processes, all of which are designed to optimise the research environment at all levels in the Agency. During this phase, line management may fill scientist vacancies and abolish positions, obligate and disperse funds, and develop agreements with outside organisations. As the cost of research continues to increase, there is a risk of losing resources to support important projects; thus, there is constant pressure to maximise efficiency, enhance collaborations, and accurately target the most important research.

Several mechanisms are in place to ensure that ARS research meets customer and stakeholder needs and is of high quality and impact. Included in these mechanisms are annual evaluations of individual scientist performance, annual reports of research progress, and yearly National Program reports that compile the best project accomplishments for a broader audience. If midcourse adjustments are necessary to avoid duplication of research and address gaps in research for new and emerging priorities, National Program Leaders have the authority to shift research objectives to meet these priorities, in consultation with project scientists and line management. For example, the finding in 2007 of orange rust (caused by Puccinia kuehnii) in Florida sugarcane, was the first report in the Western hemisphere, and prompted immediate attention to this new and serious disease.
Phase IV: National program retrospective assessment: 5-Year programs

Near the end of the project’s 5-year life, the annual reports from each of the program’s projects is summarised in a comprehensive Assessment Report, which looks at the past 5 years of accomplishments to compare against what was outlined in the Action Plan. This National Program assessment process (Retrospective Review) plays a key role in both retrospective evaluation and future priority setting in ARS. This report is used by an external panel of university and industry experts from relevant scientific disciplines to evaluate success of the National Program’s performance in the prior 5-year cycle.

The panel assesses the National Program’s impact and its delivery of information, knowledge, and technology that meet customer expectations, as determined by actual impact or progress toward anticipated benefits to end-users, scientific communities, and/or broader society as outlined in the Action Plan. After evaluating the compiled accomplishment summaries, the panel assesses the value of the research that has actually been conducted. The panel prepares a written report and makes recommendations for future research priorities. One outcome of the panel’s Assessment Report is that the National Program team has tangible, independent judgment and commentary of the previous 5-year’s research agenda, and a basis upon which to update the vision, direction, focus, and rationale of the research agenda (Action Plan) for the next 5 years.

ARS continually monitors the quality of its work to meet Federal requirements and ensure public accountability. These retrospective assessments reveal how well programmatic goals were met, whether any deviations from plans proved productive, and how future research can be focused on unmet needs.

The nature of high-risk, long-term research is that such endeavours may lead to applications only after many years, and many factors beyond the Agency’s control can affect ultimate use by producers, processors, consumers, or policy makers. Thus, ARS strives to identify ways to assess performance, impact, or value beyond simple metrics of technical inputs and outputs. For example, programs like breeding for cold tolerance for sugarcane, adaptation to marginal soils, and application of genomics for enhancing the breeding program are long-term programs to which ARS is committed for the future sustainability of sugarcane in the United States.

The key building block for any performance assessment is the project annual reports, which describe the project’s research progress and accomplishments each year. This information is used by management at all levels of the Agency, and it also informs the public about ARS progress and accomplishments.

Audiences of the annual reports, which are posted on the ARS Web site, include Congress; the White House Office of Management and Budget; stakeholders, customers, and other scientific agencies and scientists; and the general public.

Conclusions: ARS vision for the future of sugarcane research

ARS sugarcane research at a glance

ARS has a long history of international sugarcane research cooperation, aimed at improving productivity in the United States and abroad, and developing new markets for the various products that can be produced from sugarcane and other agricultural crops grown in the United States. As pressures mount on global agriculture to solve the world’s need for food and fuel in a sustainable fashion, interest in sugarcane has increased.

The success of these programs is due to their specific resources, diverse talents, and to the rich local, national, and international collaborations that are characteristic of these programs.

Primary ARS research programs for breeding, pathology, entomology, agronomy, physiology, and production at Houma and Canal Point have a long and productive history of collaborations with their respective university and industry partners. Although they are both located in a subtropical climate, their growing conditions are so different that surprisingly, in the history of
the breeding programs, only two cultivars (CP 65-357 and CP 89-2143) have been grown successfully in both states. Cultivars have traditionally been released for high sugar yield and adaptability to the local environment, but recently cultivars more suited for use as biofuels have been released. The ARS location in Miami, Florida houses the world sugarcane collection that conserves, protects, and distributes sugarcane and related germplasm to ensure genetic diversity for breeding programs worldwide.

Both Canal Point, FL and Houma, LA breeding programs have contributed significantly to international sugarcane programs through the direct use of commercial cultivars and through use of parental clones for breeding. For example, in Central America, where the climate is more similar to that of Florida, approximately 50% of the acreage in commercial production is with cultivars developed by the CP (Canal Point) USDA-ARS Sugarcane Field Station. There has also been extensive international collaboration, training of scientists and technology transfer with ARS research programs. Likewise, the Commodity Utilisation Laboratory in New Orleans, LA has made important contributions to improved industrial processing of sugarcane, and improved measurement and reduction of sugarcane deterioration.

Current ARS research priorities are listed below:

- Development of high yielding, widely adapted breeding lines and cultivars for sugar and bioenergy that yield well on varied environments to include marginal lands;
- Evaluation of complementary crops that can be grown as feedstocks with sugarcane for the year-round processing of biofuels;
- Association genetics and molecular marker development to advance conventional breeding programs;
- Precision agriculture and remote sensing;
- Mechanical harvesting and use of chemical ripeners;
- Resistance to a constantly changing array of disease, insect, and weed pests;
- Sugar chemistry, physiology, chemical engineering and impact on harvesting, and storage processing;
- Pathology to support the breeding program for disease resistance, detection, and monitoring; and
- Strategies for integrated and sustainable weed and insect management.

Currently, the two most serious threats to the U.S. sugarcane industry are brown and orange rust diseases, caused by the fungal pathogens *Puccinia melanocephala* and *P. kuehnii*, respectively. Orange rust in the United States is restricted to Florida at this time and, when found in 2007, was the first report in the Western Hemisphere.

There is a concerted effort by the research communities to identify useful fungicides as a short-term control measure, and sources of genetic resistance to support and advance the sugarcane breeding program. Fungicide use is not sustainable, however.

Thus, molecular and other efforts to support and advance the breeding programs are critical. A full interdisciplinary approach to this disease is vital to provide a profitable crop for the sugar industry and the new biofuel crops.

Efforts are aimed at maintaining a sustainable sugarcane industry that is responsive to the changing economics, production problems, and opportunities, and will require continued Federal, State, private, and international cooperation to be successful.
LE SERVICE DE LA RECHERCHE AGRICOLE DE L’USDA: UN PARTENAIRE PUBLIC DE LA RECHERCHE ET DU DEVELOPPEMENT POUR LA CANNE A SUCRE

Par

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MOTS-CLÉS: Programmes Nationaux, Acteurs, Gestion Matricielle.

Resumé
La recherche est la pierre angulaire d’un maintien d’une industrie agricole viable et durable. Les systèmes pour obtenir des financements, gérer et distribuer les ressources sont aussi diversifiés que le sont les systèmes pour cultiver la canne à sucre. Cet article présente un modèle de gestion des programmes de recherche agricole au niveau d’une agence fédéral. Le service de la recherche agricole (Agricultural Research Service, ARS) est la principale agence fédérale créée et abritée par l’USDA, avec comme tâche principale de mettre en place et conduire les financements publiques pour la recherche au bénéfice des États-Unis. L’ARS a pour objectifs de générer une information scientifique pertinente, significative et opportune pour une utilisation par les nombreux partenaires et acteurs de l’agence: producteurs agricoles, industries alimentaires, gestionnaires des ressources naturelles, universités et institutions de recherche sans profit. Pour garantir que ces objectifs seront bien finalisés, l’agence agricole ARS a mis en place le cycle de Programme National, un cycle d’étapes comprenant une série d’activités récurrentes. Les clients et partenaires sont activement engagés dans chaque étape/phase du processus et leurs contributions sont partie intégrante de l’orientation donnée à la recherche et son succès. L’apport d’idées, le planning, la mise en place et l’évaluation sont les 4 phases séquentielles à travers desquelles l’ARS progresse, tout en s’assurant que le processus reste de la plus haute qualité. Le cycle d’étapes relie ces activités entre-elles sur une séquence récurrente de 5 années pour garantir, au sein de l’ARS, un programme et un projet de gestion efficace et efficient. Ces efforts ont pour objectif de maintenir une industrie de canne à sucre durable et réactive au changement économique, aux problèmes de production, aux opportunités, et ceci va demander la mise en place, avec succès, d’une coopération fédérale, nationale, privée et internationale. Les bénéficiaires d’une industrie de canne à sucre durable sont les américains eux-mêmes, qui vont profiter d’un sucre et ses produits dérivés abondants et bon marché.
USDA—SERVICIO DE INVESTIGACIÓN PARA LA AGRICULTURA: UN SOCIO PUBLICO PARA LA INVESTIGACIÓN Y EL DESARROLLO DE LA CAÑA DE AZÚCAR

Por

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PALABRAS CLAVES: los Programas Nacionales, las Partes Interesadas, la Administración de Matriz.

Resumen

LA INVESTIGACIÓN es base para el mantenimiento de las industrias agrícolas sanas y sostenibles. Los sistemas para la obtención de financiación y para la administración y la dispersión de recursos son tan diversos como hay sistemas para cultivo de caña de azúcar. En este documento se presenta un modelo de gestión de programas de investigación agrícola al nivel de la Agencia Federal. El Servicio de Investigación Agrícola (ARS) es la Agencia principal de investigación agrícola del USDA y, como una Agencia Federal, se encarga de llevar a cabo investigaciones financiadas con recursos públicos para beneficio de los Estados Unidos. ARS pretende generar información científica pertinente, importante y oportuna para el uso de las partes interesadas de la Agencia: los productores agrícolas, las industrias de procesamiento de alimentos, los administradores de recursos naturales, las universidades y las instituciones de investigación sin fines de lucro. Para garantizar que se puedan conseguir estos objetivos, ARS ha implementado el ciclo del Programa Nacional, el cual es un ciclo de fases que incorpora una serie de actividades recurrentes. Los clientes y las partes interesadas participan activamente en cada fase del proceso y sus contribuciones son parte integrante en la dirección y el éxito de la investigación. Datos iniciales (de entrada), planificación, implementación y evaluación son las cuatro fases secuenciales a través de las cuales se desarrolla la investigación de la ARS, asegurando que siga siendo de la más alta calidad. El ciclo une estas actividades en una secuencia recurrente de 5 años para garantizar una gestión de programas y proyectos eficaz y eficiente dentro de la ARS. Estos esfuerzos están encaminados a mantener una industria de la caña de azúcar sostenible, que sea sensible a la evolución de la economía, y a las oportunidades y problemas en la producción, que requerirán apoyo federal continuo, así como también la cooperación internacional, estatal y privada para tener éxito. Los beneficiarios de una industria sostenible de la caña de azúcar serán los ciudadanos de los Estados Unidos que disfrutarán de azúcar y productos a base de azúcar abundantes y asequibles.
THE DSM—DEDINI SUSTAINABLE MILL: A NEW CONCEPT IN DESIGNING COMPLETE SUGARCANE MILLS

By

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KEYWORDS: Ethanol, Sugarcane, Sustainable, Bioelectricity, Biomass.

Abstract
For almost 500 years, sugarcane has been considered almost only as a raw material for sugar production. In the last decades, in Brazil, it has also been used for ethanol production. So, the complete sugarcane mill’s design evolved significantly in that direction, utilising sugarcane juice as a feedstock for sugar and ethanol processes. Recently, for environmental, economical, social, in other words, for sustainability reasons, the world started to search for new and cleaner energy sources. As a consequence, world interest in ethanol grew spectacularly, due to its environmental qualities and because it is produced from renewable biomass. That scenario changed the prospect for sugarcane: it allowed sugarcane to reach a new and higher dimension, and to generate a cycle of new businesses, derived from traditional and new products. This paper has the objective to show how that evolution is modifying and will continue to influence the complete sugarcane mill design, considering technological development and sustainability evolution. The paper describes an integrated sugarcane mill with the most advanced disruptive (breakthrough) innovations, considering the technological hierarchy of first, second and third generations, in bioelectricity, bioethanol, and integrated biodiesel production. Also, sustainability is incorporated into the concept of the mill resulting in an upgraded solution to an optimal design. In summary, the paper has the objective to show the upcoming sugarcane mill, the DSM – Dedini Sustainable Mill, designed for maximum efficiency and sustainability, producing six bioproducts, in an approach named ‘the 6 BIOS revolution’.

Introduction
How to design the industrial plant for bioenergy: the sugarcane mill
For a sugarcane mill design, some primary design parameters (input data) are necessary: sugarcane specifications; desired products; capacity of the mill; crushing period; number of effective crushing days; location and access; local conditions; standards, regulations and laws; local infrastructure; water availability, and so on (Oliverio, 2008a).

The products’ mass balances, steam, water and utilities requirements are also necessary, which must be complemented by a process flow diagram (PFD) for each product, as well as a processes and instrumentation diagram (P&ID).

All equipment to be used must be defined, specified and then quantified, followed by an overall plant layout (utilisation of the area, main facilities, road system). The plant layout will be detailed and then the following will be included: ancillary services and utilities; civil works designs; electrical and hydraulic designs including water, steam and products; instrumentation and control designs; treatment of wastewater and residues, as well as designs to meet the relevant laws and regulations.

Such requirements can be used to design different kinds and concepts of industrial plants, from the traditional to the most advanced (breakthrough) type.
This paper describes how Dedini views the recent evolution of the sugarcane industry from a technological point of view and how the mills evolution can influence and modify the factories, i.e., the concept and designs of the future industrial plants production systems.

The technological development of the sugarcane processing units has evolved towards a better use of sugarcane and new products. Initially, only sugar was produced, a solution that prevailed for almost 500 years: the first cane sugar mill in Brazil was built by Martin Afonso de Souza, in São Vicente, São Paulo, in 1532.

The sugarcane activity in Brazil remained so until the 1970s, when ethanol became another important product of the mill. Ethanol production increased dramatically in recent years. The recent and fast-growing world interest in ethanol is mainly due to its environmental characteristics and for being produced from a renewable feedstock. Furthermore, for economic reasons and taking into account the technological development, the world is seeking new, ‘clean’ (eco-friendly), sources of energy.

In this scenario, sugarcane as a biomass and renewable feedstock for the production of biofuel and bioenergy can be evaluated positively and attains a new dimension from the environmental point of view.

Considering the growing tendency for sustained development, sugarcane will generate a new cycle of new businesses.

**Traditional mill design**

The simplified flowchart in Figure 1 shows the technologies and production processes of a traditional mill for production of sugar, bioethanol and generation of surplus bioelectricity.

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**Fig. 1**—Traditional technology and production process: sugar, bioethanol and surplus bioelectricity.
As shown in the flowchart, we have the following main processes: sugarcane processing; sugar process; bioethanol process, and bioelectricity process.

**Sugarcane processing**

Sugarcane reception and cleaning – The cane to be processed is unloaded on feed tables where it is washed with water to remove the mineral impurities and then transported to the crushers by metal conveyor belts, passing through the preparation system.

Sugarcane preparation (knives: knives set and shredders) – The preparation system consists of one or two sets of knives, the first being designed to level the cane and the second to chop it with the purpose of levelling the cane bed that comes from the feed table and reduce the size of the feedstock. The shredders are used to open the cane cells to facilitate juice extraction.

Juice extraction: consists of feed, crushing and primary juice treatment. After the cane preparation, the cane feed into crushers is made by a device called a Donnelly chute (a forced-feed vertical chute).

Crushing consists of making the shredded cane pass through crushers comprised of rolls, installed in a series, usually 4 to 6 units, at a given pressure and rotation, to extract the juice contained in the cane and produce the co-product bagasse.

Traditionally, drive units are steam turbines (for crushers, knives and shredders).

The purpose of the juice primary treatment is to remove the impurities by means of cushion device and screens.

**Bioelectricity process**

After juice extraction, bagasse is obtained, which is composed of about 46% fibre, 50% water, and 4% dissolved solids. Conveyor belts transport the bagasse to be burnt in the boilers where high-pressure steam is produced. The steam produced is used to drive the turbines where the thermal energy is transformed into mechanical energy for machinery drives. In the power house, the turbine drives a generator that produces electric power to meet the internal requirements of the mill. Such bioelectricity generation can be optimised with solutions that will generate surplus bioelectricity to be used outside the mill (Olivério, 2008b).

**Sugar process**

The extracted juice is chemically treated to coagulate, flocculate and precipitate the minor remaining impurities after the juice primary treatment. In this stage, the juice treatment takes place in the following phases: sulfitation, liming, heating, settling, filtration and evaporation to obtain the syrup. After leaving the evaporators, the syrup is sent to another stage of concentration where sucrose crystals will be obtained. Next, it is centrifuged to separate the crystals from the end syrup (molasses) and this is sent to ethanol production.

The sugar crystals that are obtained go to the drying system and then will be bagged, weighed and stored.

**Ethanol process**

After the primary treatment, the juice is treated in a similar but not so intensive way as in the sugar process, and then must be pasteurised with heat and immediate cooling to eliminate contaminations and impurities. The treated juice and the molasses are mixed and form a mash that is sent to fermentation.

It is also possible that, in some ethanol processes, the syrup or molasses is individually sent to fermentation.

It is possible, too, that in certain ethanol processes the syrup or molasses is individually sent to fermentation.

Fermentation – mash fermentation is a result of the action of yeast, which first inverts the sucrose into glucose and fructose (monosaccharides) and then converts the monosaccharides into ethanol and carbon dioxide.
**Centrifugation** – After fermentation, the resulting product is centrifuged to separate the yeast from the fermented broth (wine).

**Yeast treatment** – The yeast, after centrifugation, is treated with sulfuric acid and taken to the fermenters to be reused.

**Distillation** – The wine is distilled in a sequence of distillation columns separating the water from the ethanol. This process takes place basically due to the temperature differences of ethanol and water ebulition.

For the production of hydrated ethanol, columns are used to obtain the ethanol concentration of 92.6° to 93.8° w/w. From the first column, stillage is obtained, which is typically used as fertiliser in the sugarcane crops.

**Dehydration** – To produce anhydrous ethanol, two additional columns are used to obtain the ethanol concentration of 99.3 min.° w/w. In the first column, the excess of water can be separated with the help of cycle-hexane or by using molecular sieves.

**New trends in traditional mill design**

The processes are evolving in order to obtain higher efficiencies and yields, i.e., bigger amounts of end products (biosugar, bioethanol, bioelectricity, others) from the same amount of raw material (sugarcane). Such technological evolution can be classified according to the impacts of the technology, promoting incremental or disruptive innovations, and follows a technological hierarchy of first, second and third generation (Olivério, 2008a, 2009a).

Regarding the incremental innovations to optimise the sugar and ethanol production processes, we can cite:

a) In sugarcane processing, the incremental innovations will benefit both the sugar process and the ethanol process in the same way by:
   - Substituting the cane wash process by dry cleaning, thus avoiding the loss of sugars carried by the cleaning water. This innovation avoids losses that can reach 2% of sugars;
   - Applying more efficient crushers associated with imbibitions comprised of hot water, which can raise extraction to 97% of the sugars present in the sugarcane by using a set of 6 crushers, or alternatively
   - Using the latest generation diffusers, capable of extracting 98% of the sugars.

b) In the sugar process:
   - In the conventional process, all unitary operations are performed to obtain the raw sugar. In those unitary operations, there are losses caused by sucrose inversion, caramelisation (Maillard reaction), evaporation and boiling entraining; losses in the rotary filters, and degradation, among others. When granulated refined sugar is produced by the conventional process, after the raw sugar is obtained it must be dissolved again, floated, filtered, evaporated, purified in ion exchange columns, crystallised, centrifuged, dried and stored. In these conditions, there are other losses besides those present in the raw sugar fabrication. By using the DRD process for production of granulated refined sugar, several unit operations are eliminated, as shown in Figure 2. So, there is a significant reduction of process losses that are inherent to those unitary operations.
   - Using the DRD process (Dedini Direct Refined) to produce refined sugar directly from the juice, in one crystallisation stage process, without the need of further processing at the refinery, avoids sugar losses in handling and other processes, which can be as high as 4% of the sugars. Additionally, lower production costs can be obtained with less investment and less energy consumption due to the elimination of the several stages of the traditional process. The DRD process, which produces sugar directly at the sugarcane mill and without a refinery is shown in Figure 2 and compared with the traditional process (Olivério and Boscariol, 2008; Olivério et al., 2010b).
c) In the ethanol process
  - Similar to the sugar process, avoiding sugar losses in evaporators and heat exchangers;
  - Fermentation optimisation by keeping the temperature controlled at the optimal degree for the yeasts activity with the use of absorption chiller (Boscariol, 2008; Yamakawa, 2009; Oliveira et al., 2010a).
  - The same as above, using stainless steel (instead of carbon steel) fermenters, with internal polishing, which facilitates asepsis and the microbiological control of the fermentation environment;
  - Both solutions will enable operations with fermentation yields around 92% (Figure 3).
d) In the bioelectricity process

The incremental innovation to produce maximum surplus energy leads to the introduction of new technologies that allow maximum use of the energy available at the mill and the minimum consumption of energy in the internal processes, as can be seen in Figure 4 (Olivério, 2008b; Olivério and Ribeiro, 2006; Olivério, 2008c; Olivério, 2009b; Olivério and Ferreira, 2010).

To reduce the energy required by the mill’s production processes, we can mention: electrical drive in knives and shredders; use of electrical-hydraulic or electrical-mechanical drives with use of planetary gearboxes in the mills or, alternatively, the use of modular diffusers; regenerative heat exchangers; multi-effect evaporation systems with the use of falling-film evaporators; continuous vacuum pans; use of absorption chiller (the chiller with the lowest energy consumption), which improves fermentation yields and enables a better use of energy because it introduces a chilled water stream into the mill, optimising heat exchanges; use of advanced solutions in distillation/dehydration (Boscariol, 2008; Yamakawa, 2009; Olivério et al., 2010a).

In this case, a new concept of distillery is introduced, with advanced criteria of the petrochemical industry, particularly the split-feed distillation system, which combines vacuum columns with pressurised columns, thus reducing steam consumption.

Also, the use membranes made of polymers, such as Siftek™, can save 35%–70% of energy when compared with the traditional processes, also having excellent selectivity for separation of water and ethanol, thus improving the quality of the ethanol produced. (Figure 5) (Olivério et al., 2010c).
To make the best use of the energy available in the mill, we can cite the use of almost 100% of the bagasse as a fuel (except about 6% to re-start operations); steam generation by boilers with high pressure, high temperature and high energy efficiency and the use of multi-stage condensation turbines with controlled extraction, suitable to the boiler parameters; the use of biogas from stillage as a source of energy. All those innovations permit the customisation of mills according to the investor’s objectives: mill with maximum bioethanol production; mill with maximum sugar production; flexible mill for maximum sugar/bioethanol production; or mill with maximum energy production (Olivério, 2008b; Olivério and Ribeiro, 2006; Olivério, 2008c; Olivério, 2009b).

From the beginning of the Proalcohol Program (1975), when the modernisation of the Brazilian mills began, until now, those incremental innovations brought significant productivity gains and better yields in the sugar, bioethanol and bioenergy production processes, with worldwide competitive products derived from sugarcane, as can be seen in Table 1.

As a reference and to correlate the current performance in the state-of-art with equipment and typical solutions, we include in Table 1 the products and technologies commercially available by the Dedini company, and part of its line of products.

Table 1—Evolution of the technological capabilities as a function of the equipment/technologies available.

<table>
<thead>
<tr>
<th>Equipment/Process</th>
<th>Dedini Products</th>
<th>Beginning proalcohol</th>
<th>Today</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crushing capacity (TCD) – 6 milling units X 78’</td>
<td>Shredder DH1/crusher MCD01</td>
<td>5 500</td>
<td>15 000</td>
</tr>
<tr>
<td>Fermentation time (h)</td>
<td>Batch/continuous fermentation plant</td>
<td>24</td>
<td>6 – 8</td>
</tr>
<tr>
<td>Beer ethanol content (°GL)</td>
<td>Fermentation plant</td>
<td>6.5</td>
<td>&gt; 9.0</td>
</tr>
<tr>
<td>Extraction yield (%sugar) – 6 mu</td>
<td>Shredder DH1/crusher MCD01/modular diffuser</td>
<td>93</td>
<td>97/98</td>
</tr>
<tr>
<td>Fermentation yield (%)</td>
<td>DFS-Dedini fermentation system integrating ecocooler</td>
<td>80</td>
<td>92</td>
</tr>
<tr>
<td>Distillation yield (%)</td>
<td>Destiltech plant</td>
<td>98</td>
<td>99.5</td>
</tr>
<tr>
<td>Total yield (litre hydrated bioethanol/ tonne cane)</td>
<td>Dedini complete mill technology</td>
<td>66 (*)</td>
<td>87 (*)</td>
</tr>
<tr>
<td>Total steam consumption (kg steam/tonne cane)</td>
<td>Dedini complete mill technology</td>
<td>600</td>
<td>320</td>
</tr>
<tr>
<td>Steam consumption – hydrated (kg steam/litre)</td>
<td>Destiltech plant includind split feed</td>
<td>3.4</td>
<td>1.6</td>
</tr>
<tr>
<td>Steam consumption – anhydrous (kg steam/litre)</td>
<td>Destiltech plant (+) split feed + membrane</td>
<td>4.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Boiler – efficiency (% low heat value) Pressure (ata) / temperature (°c)</td>
<td>Single drum type</td>
<td>66/500</td>
<td>89/120/540</td>
</tr>
<tr>
<td>Surplus bagasse (%) – In a bioethanol mill</td>
<td>Dedini complete mill technology</td>
<td>Up to 8</td>
<td>Up to 78</td>
</tr>
<tr>
<td>Biomethane from stillage (nm3/litre bioethanol)</td>
<td>Methax biodigestion</td>
<td>–</td>
<td>0.1</td>
</tr>
<tr>
<td>Stillage production (L stillage/L bioethanol)</td>
<td>Stillage concentration plant</td>
<td>13</td>
<td>0.8</td>
</tr>
</tbody>
</table>

(*) without considering agricultural development, that is, considering the same sugarcane sugar content.

**Designing the breakthrough mill**

When evaluated in its bioenergy aspect, sugarcane has an expressive dimension, which can surprise even the experts.

Figure 6 shows us that if we compare the amount of energy contained in sugarcane, i.e., if we measure the energy contained in the juice sugars, in bagasse and ‘straw’ (cane residues: tops, leaves and others), we will see that coincidentally the values are very similar. This would allow us to assume, in a simplified way, that the energy contained in sugarcane is: 1/3 in juice, 1/3 in bagasse and 1/3 in ‘straw’.
Now, if we compare the energy contained in sugarcane with that contained in crude oil, we have 1 tonne of clean sugarcane – corresponding to 1.2 tonnes of whole sugarcane, which contains $1718 \times 10^3$ kcal – is equal to 1.2 barrels of oil ($1.2 \times 1386 \times 10^3$ kcal).

The conclusion is that sugarcane is pure energy, but the industry has not taken advantage of its potential, mainly those energies contained in the bagasse (partially used and even so with low energy efficiency) and in cane residues (currently this energy is almost completely wasted, being usually burnt before the cane harvest).

Fig. 6—The agri-energy view of sugarcane.

Taking the 2008/2009 milling season as reference for an evaluation of the energy content of the Brazilian cane production, if all energy contained in juice, bagasse and ‘straw’ (or cane residues) were used, we would have a total annual average of energy equivalent to 1 944 000 barrels of oil/day and, in the 2010/11 season, to 2 310 000 barrels/day.

For an international evaluation of this dimension, if we compare the total potential energy contained in sugarcane (2 310 000 barrels/day) with the energy demand in some developed countries, it represents 124% of the energy consumed in oil/derivatives in the United Kingdom, 80% in Germany and 42% in Japan, which shows the relevance of this energy dimension (Figure 7).

Fig. 7—Energy contained in Brazilian sugarcane versus the oil demand in some countries.
As a conclusion of this new vision of the sugarcane potential, technological developments will be focused on the maximised use of sugarcane and the resources available at the mill.

Among all technologies under development, we point out three emerging technologies for their revolutionary impact on the sugarcane industry, which we call the ‘3 BIOs Revolution’: bioelectricity, bioethanol and biodiesel (see Figure 8).

In bioelectricity production, the new technologies seek the maximum use of the sugarcane energy, that is, the complete and optimised use of bagasse, cane residues and stillage (biogas from biodigestion).

In bioethanol production, the new technologies also look for the optimum use of sugarcane, including bagasse and cane residues as a cellulosic feedstock for the production of biofuels, especially ethanol.

And in biodiesel production, the new technologies seek the integration of its production into the sugar and ethanol mill.

Fig. 8—The 3 BIOs revolution.

The First Bio – Bioelectricity

For surplus energy generation, let’s consider three hierarchical technologies, the first generation being the technology available in the state-of-the-art; the second generation with the use of biogas from stillage and ‘straw’ as energy sources; and the third generation with the use of gas / steam combined cycle.

By using technologies of the first generation, with the most advanced technologies commercially available, in a state-of-the-art mill processing 500 tonnes of cane per hour (TCH), the production of surplus electric power is 50.7 MW (Olivério, 2008b; Olivério, 2008c; Olivério and Ferreira, 2010).
The State-Of-The-Art Mill

Figure 9 represents a diagram of the first generation technology for bioelectricity production.

![Diagram of first generation technology for bioelectricity production](image)

Fig. 9—Diagram of the first generation technology for bioelectricity production.

To obtain 50.7 MW of surplus power and introduce the state-of-the-art mill, we refer to the maximum surplus energy equation in Figure 4. By observing the part of the equation relating to the maximum use of the available energy, we will use all bagasse as a fuel (except the bagasse needed to re-start operations) in a 100 bar/530°C boiler, 89% efficiency (low heat value) which has the following technological advances:

- Single drum boilers, with combustion system and burning in suspension;
- Reaction type turbogenerators, condensation/extraction multi-stage turbines
- Automation – proper automation systems for boilers, turbogenerators and total process consumption.

If we observe now the part of minimum power consumption by the plant, it is possible to reduce the steam required by the process according to the following technological innovations:

- Use of electrical drives for knives and shredders, and electro-hydraulic or electro-mechanical drives with planetary gearboxes in crusher drives or, alternatively, use of the modular chainless diffuser, with lower specific power consumption;
- Use of regenerative heat exchangers;
- To maximise the heat recovery of the condensate and make use of the flash vapours heat;
- Use of multi-effects falling-film evaporators in thermal cascade;
• Use of continuous vacuum pans for sugar production;
• By increasing the alcohol content in fermentation to the range of 13.0% with the use of a fermentation containing absorption chiller-type cooling system to permit operation at lower temperatures (e.g. 28.0 to 30°C), steam consumption in distillation will be lower. To reduce the use of power, a lithium-bromide (LiBr) absorption chiller should be used;
• Use of split-feed distillation, which permits specific steam consumption to be reduced to levels as low as of 1.6 kg of steam/litre of hydrated ethanol;
• Use of membranes for ethanol dehydration, which also contribute to reduce steam consumption as compared with molecular sieves. Total steam required will be 2.0 kg/litre of anhydrous ethanol;
• Automation – adequate automation systems with the use of intelligent software to control all operations of the mill for optimum energy generation.

**Table 2**—Configuration for production of 50.7 MW of surplus bioelectricity.

<table>
<thead>
<tr>
<th></th>
<th>After changes</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugarcane crushed/hour</td>
<td>500</td>
<td>TCH</td>
</tr>
<tr>
<td>Amount of bagasse produced</td>
<td>136.8</td>
<td>t/h</td>
</tr>
<tr>
<td>Bagasse burnt</td>
<td>130.3</td>
<td>t/h</td>
</tr>
<tr>
<td>Steam produced</td>
<td>295.7</td>
<td>t/h</td>
</tr>
<tr>
<td>Steam consumed in the process</td>
<td>300</td>
<td>kg steam/tc</td>
</tr>
<tr>
<td>Steam pressure</td>
<td>100</td>
<td>bar</td>
</tr>
<tr>
<td>Steam temperature</td>
<td>530</td>
<td>ºC</td>
</tr>
<tr>
<td>Steam extracted at 2.5 bar</td>
<td>170</td>
<td>t/h</td>
</tr>
<tr>
<td>Steam at the pressure-reducing valve</td>
<td>0</td>
<td>t/h</td>
</tr>
<tr>
<td>Steam for condensation turbogenerator</td>
<td>118.7</td>
<td>t/h</td>
</tr>
<tr>
<td>Total power produced</td>
<td>69.9</td>
<td>MW</td>
</tr>
<tr>
<td>Power consumed by the plant</td>
<td>19.2</td>
<td>MW</td>
</tr>
<tr>
<td>Net surplus power</td>
<td>50.7</td>
<td>MW</td>
</tr>
</tbody>
</table>

Source: (Olivério and Ferreira, 2010).

**Second generation technologies**

The state-of-the-art mill makes use of the maximum energy contained in juice and bagasse. However, the energy contained in stillage and crop residues can also be used. Taking advantage of both sources is part of the second generation technologies (Olivério and Ferreira, 2010).

To make use of stillage, an anaerobic biodigestion system is required. Besides treatment of the mill effluents, it also generates biogas. This technology is already available in commercial scale. The biogas generated is sent to the burners of the biomass boiler. This additional energy in the boiler will generate more steam, which will be used in the condensation turbine. Surplus power will then increase from 50.7 MW to 55.7 MW.

Let’s consider now the use of 50% of the ‘straw’ (crop residues) as feedstock. Similar to biogas, this feedstock will be burnt in the boiler generating more steam for condensation and, therefore, more surplus electricity. The complete technology cycle (agricultural and industrial) of ‘straw’ utilisation as an energy source is under development in Brazil and is expected to be ready
for application in the short term. Boilers will be multifuels ready to use bagasse, biogas and crop residues and are already available in the market. (Figure 10).

The same other technologies seen in the first generation will be used. With the introduction of biogas and 50% of the crop residues, surplus power generation can reach 83.9 MW and, using 100% of the ‘straw’, reaches 112.1 MW, as shown in Figure 11.
Third generation technologies

Third-generation technologies represent trends in the production of bioelectricity that are under development worldwide. These technologies consist of bagasse and cane residues gasification producing synthesis gas (CO + H₂), and operating a combined cycle in the mills. In this cycle, the biogas produced from stillage and the syngas from bagasse and cane residues will be used in the gas turbine, which drives the generator and produces surplus power. The gases that leave the gas turbine are directed to a heat recovery boiler; steam generated in the recovery boiler goes to a steam condensation/extraction turbogenerator. After the development and availability of this technology in commercial scale, surplus power production can be as high as 112.1 MW. In this case, gasification of bagasse and 50% of cane residues are assumed; if 100% of the cane residues could be transported from the field to the mill to produce syngas, surplus power generation would be as high as 150 MW.

A diagram of the third generation technology is shown in Figure 12, expected to be implemented in the long term.

![Flowchart of third generation technology for bioelectricity production.](image)

The second Bio – Biofuels (mainly ethanol)

The second Bio of the ‘3 Bios Revolution’ is the production of biofuels, and let’s starts with the first generation, the optimisation of a traditional mill to a state-of-the-art mill.

Let us assume an agricultural productivity of 80 tonnes of cane/hectare, and a mill that optimises the use of juice for ethanol production, reaching 89.8 litres of ethanol/tonne of cane, totalling then 7 184 litres of ethanol/hectare of cane, as shown in Figure 13.

The first generation technologies for the optimum production of ethanol from cane juice representing the state-of-the-art were described previously in ‘New trends in traditional mill design’.

Fig. 12– Flowchart of third generation technology for bioelectricity production.
The second generation of bioethanol production will use the lignocellulosic materials, the bagasse and crop residues as additional feedstock to the cane juice (Olivério and Hilst, 2005).

The conversion processes include chemical and biological conversions by means of hydrolysis and hydrolysed liquor fermentation, which will almost permit doubling the productivity in the biofuels production for the same amount of crop land, attaining 12,824 litres of ethanol/hectare of cane, as can be seen in Figure 14.
We believe this technology will be competitive and will be implemented in a medium to long term. In Figure 15, the DHR – Dedini rapid hydrolysis semi-industrial plant is presented.

The third generation of biofuels use the thermochemical technological route to process the lignocellulosic material, bagasse and crop residues for generation of syngas and, next, the production of liquid biofuels. This technology is also called BTL – biomass to liquid, which gasifies biomass and converts the syngas via Fischer-Tropsch type reaction into liquid fuel (hydrocarbons) bioproducts such as: naphtha, gasoline, kerosene and diesel, besides other chemical products. This technology enables productivity higher than 12 834 litres of liquid biofuel per hectare of cane, as can seen in Figure 16.

It is a prospective technology in the long term with great interest and investments currently being performed in various countries around the world.
The Third BIO – Biodiesel

Biodiesel production integrated to the sugar, bioethanol and bioelectricity producing mill is also a technology with significant prospective impacts (Olivério et al., 2007).

The production of oleaginous grains (soybean or sunflower) is made in rotation to sugarcane crops during sugarcane renovation, providing the farming integration of the two crops. And the industrial integration is made with the use of bioethanol as the second feedstock for biodiesel, the use of the energy from bagasse in the biodiesel plant and the surplus bioethanol dehydration in the same installations of the ethanol mill, and sharing of utilities (Olivério et al., 2007).

Such integration permits the use of the biodiesel by the same farming sector, and can generate surplus biodiesel for sale. It happens in three stages: the first is the partial integration of the industry; the second is the agricultural and industrial integration; and the third is the processes integration of the production chains of grains and sugarcane, as shown in Figure 17.
For stages 1 and 2, the technology is already available, and the third is in the initial stage of development and will have a significant future impact on additional reduction of biodiesel and bioethanol costs. To cite possible examples of the third stage, bioethanol can be the solvent in the extraction processes of oil from grains, replacing hexane, increasing oil production and at the same time producing value-added meal with higher protein content. Additionally, some sugars present in soybean may be added to the juice, thus increasing ethanol production by the mill.

At this point it is important to emphasise that the technology for the continuous process of biodiesel production has been available by the methyl route only, particularly developed in Europe. For the biodiesel-bioethanol integration, it was necessary to develop the ethyl route in a continuous process.

The conclusion of such development was presented in July 13, 2004, during the II SIMTEC – International Symposium and Technology Exhibit of the Sugar and Ethanol Industry – held in Piracicaba, when Dedini and DeSmet Ballestra launched the pioneer process of continuous production of biodiesel by the ethyl route.

For this kind of application, Dedini sold the first biodiesel mill with this format, the Barralcool Mill in Barra do Bugres, MT, Brazil in 2005, which started operation in November 2006, Figure 18.

It should be emphasised that the Barralcool Mill is the first mill in the world that produces the 4 BIOs: biosugar, bioethanol, bioelectricity and biodiesel.

Fig. 18—Barralcool Mill – Operational flow.

The picture in Figure 19 gives an overview of the biodiesel plant integrated to the Barralcool Mill.
Fig. 19—Integrated mill with the 4 BIOs: biosugar, bioethanol, bioelectricity and biodiesel – Barralcool Mill.

**DSM – Dedini Sustainable Mill: the 6 BIOs revolution**

To meet the new world demands for sustained solutions in the economic, environmental and social issues, Dedini has developed the DSM – Dedini sustainable mill. It is a product in continuous development and was commercially available in 2008 in its first commercial stage (Olivério, 2009c).

The innovative feature of DSM is that it is a physical system, consisting, for example, of machines, tubes, tanks, and the sustainability is more evident in operational management. The question then is: How can a set of physical items contribute to sustainability?

This question is analysed in the following text, and is represented in Figure 20.

In the economic aspect, the DSM is competitive in the free market, without any kind of subsidies.

Regarding the environmental aspect, the solutions include minimal, or zero, water and energy demands, non-generation of polluting wastes, including the reduction of greenhouse gases (GHG) emissions, minimised use of feedstocks and inputs from non-renewable and polluting sources – it is a zero-wastewater, zero-residues, zero-odours and minimum emissions mill.

These solutions should meet the environmental standards and regulations so as to contribute to mitigate or eliminate the impacts on the environment and provide sustained farming.

The Dedini sustainable mill allows an easier implementation and management of ISO 14000 system.

Regarding the social aspect, the equipment, processes, materials and facilities are arranged in such a way to facilitate operations, materials handling and compliance with standards and regulations, providing comfort, safety, hygiene and good health conditions to the workers.

The operators can work with minimal physical effort, as far as ergonometric concepts are concerned, providing the correct man/machine interaction. Also, the use of automation is
considered by means of intelligent and integrated softwares, at MES – Manufacturing Execution System level, which links shop floor operations to management. The Dedini sustainable mill also includes the integration to the management systems (ERP) to facilitate the implementation and management of the SA 8000 system.

This work will focus on environmental issues, highlighting the contribution of DSM to mitigate the greenhouse gases released in the atmosphere, particularly in the direct reduction of CO₂ emissions, its capture and avoidance, contributing to reduce the factors that are promoting climate change.

With the introduction of DSM’s new technologies, this kind of mill will generate an ethanol with significant reduction of carbon emissions when compared with the ethanol produced in a traditional mill.

To illustrate the cycle of emissions of greenhouse gases (GHG), we demonstrate in the next infographic, as can be seen in Figure 21, the ethanol complete life cycle of production, corresponding to equivalent 1000 litres of ethanol, showing the absorbed, generated and avoided direct emissions in a traditional mill, from the sugarcane plantation to harvest (generated emission), passing through the sugarcane growth (absorbed or captured emission), the sugarcane processing to transform it into ethanol (generated emission), bioelectricity generation (avoided emission), ethanol transportation from the mill to the distributor (generated emission), and finally the use of ethanol in vehicles (generated emission), in a blend of 25% with gasoline (Brazilian blending standard).

This infographic shows that, in the complete cycle, the difference between the generated emissions and the absorbed/avoided emissions is 260 kg of CO₂/m³ of ethanol. However, when ethanol is used in vehicles as a substitute for gasoline, the emissions that would be released by gasoline in its complete cycle would be avoided, corresponding to 2280 kg CO₂/m³ of equivalent
ethanol. So, in the final balance, we have 2.28 kg of avoided CO$_2$/litre, when ethanol replaces gasoline as an automotive fuel, less 0.26 kg CO$_2$/litre, corresponding to a direct reduction of 2.02 kg of CO$_2$/litre of ethanol.

![Image of diagram](image1.png)

**Fig. 21**—GHG emissions captured/avoided considering ethanol complete life cycle when produced in a traditional mill. Source: UNICA website, Accessed 28/07/2009.

To conclude, the use of the ethanol produced in the Brazilian reference mill (traditional) avoids emissions of 2.02 kg of CO$_2$/L of equivalent anhydrous ethanol, with mitigation of 89% of direct emissions when compared with gasoline (traditional mill), as shown in Figure 22 (Unica, 2009).

![Image of diagram](image2.png)

**Fig. 22**—Emissions balance flowchart in the anhydrous ethanol life cycle when produced in a traditional mill. Source: Unica, 2009.
The big question that arises is: How can the mills contribute to further mitigation of direct emissions of GHG in the agricultural and industrial sectors?

The answers to this question are as seen in Figure 23.

First, taking the traditional mill as reference, technological innovations are introduced to optimise energy efficiency with the purpose of maximising surplus MW generation (Chapter 4 – bioelectricity: first generation); increase the overall yields to maximise productivity (litres of ethanol/tonne of cane – Chapter 4 – bioethanol: first generation); provide CO₂ direct reduction by using internal processes in the mill with minimal CO₂ emissions; increase avoidable emissions by using the CO₂ produced by the mill (for example, the CO₂ from ethanol fermentation) to replace fossil CO₂, to be used in the production of other products such as sodium bicarbonate; contribute to the reduction of emissions in farming by avoiding the use of products that release CO₂, like fertilisers and diesel; reduction of CO₂ emissions by eliminating the cane burning before harvest.

Another reference is the bioethanol – biodiesel integration in a 3 BIOs mill, where the contribution to CO₂ mitigation may occur in several links of the production chain, particularly considering the agricultural and industrial integration of the two processes, as seen in Figure 24.

In this integration, mitigations occur as a function of the following factors: maximisation of surplus bioelectricity production (MW) (bioelectricity: first generation); maximisation of yields (litres of ethanol/tonne of cane – bioethanol: first generation); substitution of the diesel oil used in farming for biodiesel from renewable origin (biodiesel integrated to the sugar and ethanol mill); double use of land by producing grains (mainly soybean) in rotation with sugarcane crop; utilisation of the bioenergy from bagasse in the biodiesel plant replacing the energy from fossil origin that prevails in the traditional biodiesel plants (biodiesel integrated to the sugar and ethanol mill); use of
the renewable ethyl route instead of the methyl route, because the methanol traditionally used is from fossil source (bioethanol integrated to the sugar and ethanol mill); reprocessing of the surplus bioethanol plus water in the dehydration process of the mill by using the energy from bagasse instead of the fossil energy that is predominant in the traditional dehydration plants (bioethanol integrated to the sugar and ethanol mill). (Olivério et al., 2007).

As seen, the introduction of the new technologies described herein, particularly the 3 BIOs revolution, contribute to the reduction of the greenhouse gases and to the mitigation of the causes of global warming and other climate changes.

Other important aspects for the improvement of sustainability are also incorporated in the mill designs.

It is a fact that sustainability will have an increasing influence on the concept and design of new mills; in this context, the DSM in the state-of-the-art stage is a solution in line with this tendency. New sustainability indicators are being considered for evaluation of the processes efficiencies, to identify the levels of energy and water demand to evaluate different kinds of input materials or consumables, besides wastes and residues. The DSM is part of this context for using new technologies that increase sustainability, and producing other BIO-products as will be seen next. As a preliminary reference configuration, the 4 BIOs mill will be adopted – biosugar, bioethanol, bioelectricity and biodiesel – to which another BIO will be incorporated, the first being the fifth BIO: Biowater.

The Fifth BIO – Biowater

An important step towards sustainability was the introduction of the water self-sufficient mills in 2008 and a more advanced solution, the water-producing mills.

These concepts are a breakthrough in the world market: the water self-sufficient mills do not demand water-supply systems, i.e., water is not supplied by rivers, lakes, springs or wells. Only the
water contained in sugarcane is sufficient to meet the needs of the mill processes (Olivério, 2009c; Olivério et al., 2010d).

An evolution of this concept is the technology optimisation which allows the mill to recover more water from the sugarcane than it will use internally and so it can export the surplus water for other uses. On the average, there are 700 kg of water in one tonne of sugarcane. A typical Brazilian mill (Unica, 2005) demands 1830 kg of intake water to process one tonne of cane, and by adding the water contained in the sugarcane, a total of 2530 kg of water is used per tonne of cane. This amount meets the usual losses in the sugar and ethanol production processes, i.e., 1919.57 kg (evaporation, cane wash and others) and the water that is incorporated in the mill’s products and by-products (stillage and others) totalling 610.43 kg (Figure 25).

Assuming as reference the production of 80 litres of ethanol/tonne of cane, the intake water specific consumption from supply sources will be 22.9 litres of water/litre of ethanol.

![Fig. 25—Water consumed by the traditional mill.](image)

When we look for possible savings in water-consuming processes, we have three natures of processes and demands:

a) Processes that demand water and can be substituted for other non-demanding processes, e.g., sugarcane dry cleaning instead of cane water cleaning.

b) Processes where there is loss of water that can be recovered, such as in evaporation; with the use of efficient condensers and cooling towers, water can be recovered and reused.

c) Traditional diluted processes that can operate with higher concentration or concentrated stream processes, such as in fermentation with higher alcohol contents.

With this concept in mind, other water-saving solutions are incorporated in the mill’s design: indirect heating in distillation; cooling towers; condensate monitoring and entrainer separator, etc. As a result, we have a new mill design: the Hydro Mill, the water self-sufficient mill,
as can be seen in Figure 26. The second revolution stage of this Hydro Mill, and the BIOwater production will be seen together with the sixth BIO product.

The Sixth BIO – Biofertiliser

The sixth BIO is BIOFOM®, an organomineral fertiliser.

Based on the self-sufficient mill, we can move forward to the water exporter mill by incorporating the sixth BIO in the mill design.

In this case, stillage concentration to about 65° Brix is introduced into the mill to recover and reuse water. A fertiliser blending and pelletising plant is incorporated to the mill which will produce BIOFOM and recover the remaining water for further use (Olivério, 2009c; Olivério et al., 2010e).

BIOFOM results from the mixture of the mill process residues that have fertilising properties like concentrated stillage, filter cake, boiler ashes and soot.

As a result, we have a more advanced design, the Hydro Mill Plus, the water producing mill that exports water for other purposes.

By producing biowater, the mill condition is reversed: from a big water waster in the traditional mill – 22.9 litres of water/litre of ethanol, to water exporter in DSM – 3.6 litres of exported water/litre of ethanol (Figure 27).
Fig. 27—The hydro mill plus, the water exporting mill.

The concern with non-renewable natural resources, like fossil fuels, mainly crude oil, has forced many companies to seek a solution to replace these resources in the production processes. In this scenario, the DSM incorporates BIOFOM\textsuperscript{TM} (organomineral biofertiliser), a fertiliser produced from the residues of the sugarcane processing and a solution to replace the mineral fertilisers used in sugarcane crops.

The product resulting from the mixture of these residues, with the addition of chemical nutrients, is processed into an organomineral fertiliser containing the elements that can be dosed according to the specific needs of the soil for sugarcane culture, besides improving the physical, chemical and biological conditions of the soil due to the organic matter, as can be seen in Figure 28 and 29.

Fig. 28—BIOFOM: organomineral biofertiliser.
In addition, because it is a granular fertiliser, BIOFOM permits an easier application if compared to the distribution of stillage in the cane crop, thus reducing investments and costs.

To evaluate the performance of BIOFOM, experimental tests were conducted at ESALQ, Escola Superior de Agricultura Luiz de Queiroz – USP (São Paulo University), which showed the best growth and productivity was afforded by the use of BIOFOM. (Figure 29) (Olivério, 2009c; Olivério et al., 2010e).

This can be explained by the aggregation of soil particles, providing nutrients for the culture, favouring the development of microorganisms (fungi and bacteria) and greater retention of water – taking part in the water requirements of plants during the dry season.

**DSM benefits regarding GHG emissions**

In the current context, the world is releasing a huge amount of greenhouse gases (GHG), resulting in global warming, mainly because of the use of fossil fuels.

Any solution focused on GHG reduction should be prioritised for meeting social and environmental sustainability, besides its economic feasibility.

New technologies already available for sugarcane processing in the mills can contribute to the reduction of GHG emissions. In line with this demand, Dedini has developed new technologies to mitigate GHG emissions.

These new designs contribute to sustainability for introducing bioproducts, in a methodology that the company calls ‘The 6 BIOs revolution’ (biosugar, bioethanol, bioelectricity, biodiesel, biofertiliser and biowater), integrating them so as to optimise the social, environmental and economic feasibility (Figure 30).

In the Dedini Sustainable Mill concept, the pursuit of sustainability requires the continued development of increasingly upgraded solutions.
Fig. 30—The 6 BIOs – DSM – Dedini Sustainable Mill in continuous development.

The complete integration of farming and industry to the integrated production and utilisation of the 6 BIOs permits an effective and significant contribution to the mitigation of the GHG, as can be seen in Figure 31.

Fig. 31—The DSM impact to mitigations of GHG.
The technological evolution can be evaluated by analysing the life cycle of ethanol production/utilisation, considering the equivalents of direct emission of CO₂ in the diverse phases of the cycle: sugarcane production, comprising the activities of planting, cultivation and harvest; sugarcane processing in the mill; distribution of ethanol from the mill to the refuelling stations; and use of ethanol as an automotive fuel.

The absorption, reduction or avoidance of emissions is also contemplated: absorption occurs in the sugarcane sprouting, growth and maturation; avoidance, in the sale of surplus bioelectricity to the grid, avoiding the use of fossil fuel for the production of the same electricity.

With these data, it is possible to calculate the complete balance of direct emissions in the life cycle from the production to the use of ethanol in the DSM.

As a result, three stages of evolution are presented, according to the introduction of new technologies, some already developed and available in the market, some in development to be introduced in the medium term and others to be developed in the long term.

In each stage, the benefits for the mitigation of GHG are presented, measured by the net emissions avoided in relation to the emissions released by gasoline.

**Results and impacts of GHG emissions**

The DSM in the state-of-the-art stage will reduce CO₂ emissions using technologies commercially available, i.e., those that: raise productivity from 86.3 litres of ethanol/tonne of cane (in the traditional mill) to 89.9 L/tonne (bioethanol: first generation); increase surplus power generation from 9.2 MW to 50.7 MW (bioelectricity: first generation); produce biodiesel integrated to the mill to replace 5% of the diesel oil consumed by trucks and 30% of that consumed by tractors, according to Figure 17 and 18 (biodiesel production integrated to the sugar and ethanol mill – first stage); introduce Biofom – organomineral biofertiliser, replacing most of the mineral fertilisers; make use of the water contained in the cane (producing biowater), with these technologies implemented by the mill, **2.56 kg of CO₂/L of equivalent ethanol** are avoided, which mitigate **112%** of emissions (DSM state-of-the-art) (Figure 32).

The upcoming DSM (near future) considers the use of oil and 50% of the sugarcane crop residues as energy with additional technologies, other than those of the DSM state-of-the-art, and will avoid **3.02 kg of CO₂/L of equivalent anhydrous ethanol**, with mitigation of **132%** of emissions (DSM Plus).

In this case, bioelectricity production rises to 83.9 MW, corresponding to the second generation, according to Figure 11 (bioelectricity of second generation), and also as can be seen in Figure 33.
Another technology that may have a significant mitigation impact is the use of the CO$_2$ generated in the fermentation process, together with boiler gases after purification as, for example, industrial gas, as already used in: food freezing/cooling, beverage carbonation, polyurethane foam expansion, textiles neutralisation, modified/controlled atmosphere, metallurgical furnaces, water hardness increase, pulp wash in the pulp and paper industry, pH control in paper, leather de-liming, video laparoscopy, high power laser, supercritical fluid chromatography, soap acidulation, carbon fertilisation, dry ice, sand moulding, among others.

Another example of application is the production of sodium bicarbonate, as demonstrated in an industrial plant supplied by Dedini (Figure 34).
All these applications are possible, but not always competitive. Another aspect is that these solutions have limited application, because the market for each of them and even as a whole is small to absorb all the CO2 that is generated in the production of Brazilian ethanol.

Therefore, it is necessary to develop new competitive applications so that one can consider that this CO2 avoids the use of the CO2 from fossil fuels.

For these reasons, we will include this contribution in the ‘Potential DSM’, the next stage of the DSM, viable in the long term if we succeed in making use of the carbon dioxide from fermentation, therefore contributing to the mitigation of GHG for every litre of ethanol produced and consumed.

The Potential DSM, with the introduction of new technologies, the use of 100% of crop residues as energy to produce 112.1 MW (Bioelectricity: second generation), the use of the CO2 generated by fermentation (as mentioned earlier) and replacement of 100% of the diesel oil by biodiesel that will occur after adaptation of truck and tractor engines, will have an avoided emission of 5.0 kg of CO2/L of equivalent anhydrous ethanol, mitigating 219% of the emissions released by gasoline (Potential DSM-1) (Figure 35).

Fig. 35—Mitigation effect of the DSM in a long term future – Potential DSM – 1.

Assuming the previous potential DSM – 1 and the foreseen technologies for the third generation of bioelectricity, we will have 150 MW of surplus and, considering the additional CO2 produced (by gasifying all bagasse and cane residues and burning this syngas at the gas turbogenerator), replacing fossil generated CO2, we will have a mitigation of 5.47 kg of CO2/L of equivalent anhydrous ethanol and mitigation of 240% of the emissions released by gasoline (Potential DSM–2) (Figure 36).

Fig. 36—Mitigation effect of the DSM in a long term future – Potential DSM – 2.

**Conclusion**

This work showed the evolution of the mill design from bio-initial stage as a traditional sugar factory, passing through the introduction of new technologies to enhance bioethanol and bioelectricity production up to the state-of-the-art mills.
Then, it was shown how disruptive innovations (breakthroughs) have been applied in the 3 BIOs route, which will revolutionise the industry and improve even more the yields and productivity, in accordance with such trends. Also, it was shown how all those developments permit a significant reduction of emissions, even much higher than ethanol already does in the traditional mill, and that the new trends are aligned with GHG mitigation.

Finally, Table 3 presents a summary of the impacts on the mitigation of GHG as a result of the technologies that have been introduced into the Dedini Sustainable Mill, from the state-of-the-art to a potential and promising outlook that can be expected with the technological trends in development.

<table>
<thead>
<tr>
<th>Type of Mill</th>
<th>Avoided emissions kg of CO₂/litre of equivalent ethanol</th>
<th>% of emissions reduction in relation to gasoline</th>
<th>Technological features</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – Traditional mill (reference)</td>
<td>2.02</td>
<td>89</td>
<td>Traditional mill (B₁ + B₂ + B₃)</td>
</tr>
<tr>
<td>2 – DSM (state-of-the-art)</td>
<td>2.56</td>
<td>112</td>
<td>Mill with 1st generation – max. surplus MW generation; max. overall yields of ethanol and sugar; min. CO₂ emissions in the process; increase of avoided emissions with the substitution of diesel oil; reduction of emissions in farming avoiding the use of mineral fertilisers with BIOFOM (B₁₀ + B₂₀ + B₃₀ + B₄ + B₅ + B₆)</td>
</tr>
<tr>
<td>3 – DSM Plus (near future)</td>
<td>3.02</td>
<td>132</td>
<td>Use of 50% of cane residues as feedstock for surplus MW production; increase of avoided emissions due to the reduction of cane burning and higher generation of surplus bioelectricity. (B₁₀ + B₂₀ + B₃₀ + B₄ + B₅ + B₆ + B₇)</td>
</tr>
<tr>
<td>4- Potential DSM 1</td>
<td>5.00</td>
<td>219</td>
<td>Use of 100% of cane residues as feedstock for energy production; substitution of 100% of diesel oil by biodiesel; increase of avoided emissions by eliminating cane burning; and replacement of fossil CO₂ by CO₂ from fermentation (B₁₀ + B₂₀ + B₃₀ + B₄₀ + B₅ + B₆ + B₈)</td>
</tr>
<tr>
<td>5- Potential DSM 2</td>
<td>5.47</td>
<td>240</td>
<td>Use of 100% of cane residues and bagasse as feedstock for gasification to produce surplus MW (3rd generation); substitution of 100% of diesel oil by biodiesel, increase of avoided emissions by eliminating cane burning; and replacement of fossil CO₂ by CO₂ from fermentation and from burning syngas from gasification of all bagasse and cane residues (B₁₀ + B₂₀ + B₃₀₀₀₀ + B₄₀ + B₅ + B₆ + B₈₀)</td>
</tr>
</tbody>
</table>

B₁ = Biosugar; B₂ = Bioethanol; B₃ = Bioelectricity; B₄ = Biodiesel (5% and 30%); B₅ = Biowater; B₆ = Biofertiliser; B₇ = use of cane residues as feedstock (50%); B₈ = Use of CO₂ from fermentation replacing fossil generated CO₂; B₁₀ = Optimised Biosugar; B₂₀ = Optimised Bioethanol; B₃₀ = Optimised surplus Bioelectricity; B₄₀ = Optimised Biodiesel (100%); B₇₀ = use of cane residues as optimised source of energy (100%); B₃₀₀₀ = Optimised surplus bioelectricity by using bagasse and 50% cane residues as fuel; B₃₀₀₀₀ = Optimised surplus bioelectricity by using bagasse and 100% cane residues as fuel; B₃₀₀₀₀₀ = Optimised surplus bioelectricity by gasifying bagasse and 100% cane residues and using as fuel; B₈₀ = Use of CO₂ from fermentation and from burning syngas from gasification of all bagasse and cane residues replacing fossil generated CO₂
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L’USINE DE DEDINI—DEDINI SUSTAINABLE MILL: UN NOUVEAU CONCEPT DANS LA CONFIGURATION INTEGRALE DES USINES DE CANNE A SUCRE

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MOTS-CLÉS: Ethanol, Canne à Sucre, Durabilité, Bioélectricité, Biomasse.

Résumé
PENDANT Presque 500 ans, la canne à sucre a été considérée presque exclusivement comme de la matière brute destinée à la production de sucre. Dans les dernières décennies au Brésil, elle a aussi été utilisée pour la production d’éthanol. Dans ce contexte, la configuration de l’usine de canne a évolué de manière significative pour s’adapter à de nouvelles utilisations du jus de canne, non seulement pour le sucre mais pour le processus de fabrication de l’éthanol. Récemment, pour des considérations environnementales, sociales et économiques, en d’autres mots de durabilité, le monde a commencé à rechercher des énergies nouvelles et plus propres. De ce fait, l’intérêt mondial pour l’éthanol s’est accru de façon spectaculaire, dû à ses qualités environnementales et aussi parce qu’il est produit à partir de biomasse renouvelable. Ce scénario a changé la perspective de la canne à sucre : il a permis à cette culture d’atteindre une nouvelle et plus large dimension, et de générer des opportunités commerciales à partir des produits traditionnels et nouveaux. Cet article a pour objectif de montrer comment cette évolution modifie et va continuer à influencer la configuration complète de l’usine sucrière, considérant le développement technologique et une évolution vers plus de durabilité. L’article décrit une usine de canne à sucre intégrée avec des innovations très en pointes voire révolutionnaires, considérant la hiérarchie technologique de la première, la deuxième et la troisième génération en bioélectricité, bioéthanol et la production intégrée de biodiésel. La durabilité est aussi incorporée dans ce concept de l’usine apportant une solution adaptée pour une configuration optimale de l’usine. En résumé, l’article a l’objectif de présenter l’usine de canne à sucre à venir, la DSM – Dedini Sustainable Mill (l’usine durable de Dedini), configurée pour un maximum d’efficacité et de durabilité, réalisant six bioproduits, dans une approche appelée «la révolution des 6 BIOS »).
EL DSM—DEDINI FABRICA SOSTENIBLE: UN NUEVO CONCEPTO
EN EL DISEÑO COMPLETO DE FABRICAS DE AZUCAR

Por

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PALABRAS CLAVE: Etanol, Caña de Azúcar,
Sostenible, Bioelectricidad, Biomasa.

Resumen
Durante casi 500 años, la caña de azúcar ha sido considerada en su mayoría sólo como materia prima para la producción de azúcar. En las últimas décadas, en Brasil, también ha sido utilizada para la producción de etanol. Así, el diseño completo de las fabricas de caña de azúcar evoluciono considerablemente en esa dirección, utilizando jugo de caña de azúcar como una materia prima para los procesos de azúcar y etanol. Recientemente, por razones ambientales, económicas, sociales, en otras palabras, por razones de sostenibilidad, el mundo comenzó a buscar fuentes de energía nuevas y más limpias. Como consecuencia, el interés mundial en etanol creció espectacularmente, debido a sus cualidades medio ambientales y porque se produce a partir de la biomasa renovable. Esta situación cambió la perspectiva de la caña de azúcar: permitió a la caña de azúcar alcanzar una dimensión nueva y superior, y generar un ciclo de nuevas empresas, derivadas de productos tradicionales y nuevos. Este documento tiene el objetivo de mostrar cómo esa evolución está modificando y continuará influyendo el diseño completo de la fabrica de caña de azúcar, considerando el desarrollo tecnológico y la evolución de sostenibilidad. El documento describe una fabrica integrada de caña de azúcar con las más avanzadas innovaciones disruptivas (avance), considerando las jerarquías tecnológicas de primera, segunda y tercera generaciones, en bioelectricidad, bioetanol y producción de biodiesel integrado. También, la sostenibilidad está incorporada en el concepto de la fabrica, resultando en una solución actualizada para un diseño óptimo. En resumen, el documento tiene el objetivo de mostrar la próxima fabrica de caña de azúcar, la DSM-Dedini fabrica sostenible, diseñada para la máxima eficiencia y sostenibilidad, produciendo seis bioproductos, en el marco de una estrategia denominada "la Revolución de 6 BIOS".
DESIGNING, PRODUCING AND PROCESSING ‘ULTIMATE’ VARIETIES OF SUGARCANE

By

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KEYWORDS: Sugarcane Varieties, Sugarcane Breeding,
Sugarcane Composition, Chromatographic Analysis, Alternative Products

Abstract

Many sugar industries, beet and cane, would predict that in the future they will produce a wide range of products, which could include sugar. To realise this prediction, new varieties must be designed, production practices improved and alternative processing techniques developed. Sugarcane breeding and selection has moved far beyond the ‘old days’ of crossing the best parents and hoping to select the best segregate as a potential new variety. Modern breeding procedures and biotechnology offer greater efficiency. Typically, varieties are selected on the basis of high yield of sugar and characteristics important to agronomic production and pest resistance in each growing region. The typically measured juice quality characteristics of brix and pol along with tonnage, ratooning ability and fibre content can predict yield of sugar per unit area. It is anticipated that the ‘ultimate’ variety of the future will involve much more detailed analysis than the typically measured characteristics. Once produced, high yielding varieties for various products need to be grown in a sustainable manner that provides maximum production with minimal environmental and economic impact. Processing of these varieties will need to accommodate the specific product(s) being produced whether sugar, energy, some other product or some combination of these. To demonstrate the importance of quality characteristics of future varieties, the Sugar Processing Research Institute has investigated the presence of components that could either enhance or inhibit production of various products from sugarcane. Significant variability among and within species of sugarcane and related genera have been found for starch, polysaccharides, ash, cations, invert sugars and other parameters. This paper includes these data and the potential importance of these parameters in future varieties, its importance in a sustainable production system and its importance in processing needs.

Introduction

While we often like to use the word ‘traditional’ when we speak about issues regarding the sugar industry, the fact is sugarcane industries around the world always find themselves as part of a dynamic situation. Papers that deal with sugarcane breeding and the history of breeding traditionally start with discussions about Indonesia and Barbados that once had thriving sugar industries.

Today, tradition is somewhat gone as Indonesia’s sugar production is less than half of its total use and Barbados, like much of the Caribbean, is struggling to survive as a sugar industry. Both still have significant breeding efforts, but the tradition of the industry has certainly changed.

Papers dealing with sugar industry production traditionally have listed sugar and molasses as the saleable products produced from an industry. Over the last decade we now find other columns in production tables; these include ethanol, building products from bagasse, electricity produced,
betaine (sugarbeets), acid production, and others. None of these products are new, but they aren’t part of what one remembers as the traditional sugar industry.

Production practices and pest control, while often thought of as traditional within each country, have changed, oftentimes drastically, to meet changing pest problems; climatic conditions; environmental regulations; prices for energy, fertiliser and crop protection chemicals; and, sustainability issues. When one considers this dynamic situation, the word ‘tradition’ becomes less meaningful.

This brings us to the future. What will industries in the near and long-term future be producing? How will the varieties for these products vary? What type of production practices will be required for these newer varieties with increased concerns about sustainability and the environment? How will processing practices change to most efficiently produce these products?

Much is already known about the variability and heritability that exist with yield and sugar content in sugarcane (Richard and Henderson, 1976; Heinz, 1991). Monosaccharides (glucose and fructose), total polysaccharides (gums), starch, colour, and organic acids present in the juice vary with variety, climatic conditions, extraneous matter content, age of cane, location, degradation, and other factors (van der Poel et al., 1998; Clarke and Godshall, 1988; Zhou, 2007).

Heritability of these factors is not as well understood as for major components such as sucrose content. The future of sucrose and its potential use along with other products from the sugarcane plant have been discussed for many years (Paturau, 1969; Purchase, 1995; Godshall, 2009). However, little emphasis has been given to directed breeding of sugarcane for these products.

Sugar Processing Research Institute (SPRI), located in New Orleans, USA, has attempted to answer questions concerning component analysis of sugarcane and how that might impact future breeding of sugarcane varieties.

SPRI is a unique research organisation, representing international sponsors that produce sugar, provide services and technology to the sugar industry, or use sugarcane or sugarbeet products. It conducts research in areas important to quality products coming from these segments of the sugar industry. As such, evaluation of issues important to sugar processing is a mainstay of this research organisation.

Recently, one project of SPRI was to evaluate sugarcane germplasm and sugarcane harvest treatments for potential impact on production of all products.

The objective of this research was to examine the varying levels of components contained in the juice of these varieties and harvest treatments that could then be considered as enhancing or inhibiting the production of potential final products including alcohol and sugar.

Finally, consideration was given to how varieties with these varying components could then fit into a sustainable production system and be most efficiently processed.

Materials and methods

In the first phase of the research in 2007, in collaboration with the USDA Sugarcane Research Unit (USDA SRU) in Houma, LA, SPRI began studying three sugarcane varieties. Two were commercially grown varieties, HoCP96-540 and Ho95-988, while L79-1002 was a wild type now referred to as ‘energy cane’. Each variety was harvested under three conditions: A- total biomass consisting of tops, side leaves and stalks; B- only side leaves and stalks with the tops removed; and C- only stalks with the tops and side leaves removed. Four replications were harvested by hand for each treatment, each of which was a 15-stalk sample. The samples were milled by the USDA SRU laboratory and the juice obtained for a typical analysis. The typical analysis usually performed to determine the value of sugarcane includes brix, sucrose, fibre and total recoverable sugar (TRS).
Duplicate juice samples from variety/treatment samples were then composited and analysed in greater detail at the SPRI laboratory for the parameters of pH, brix, total polysaccharide, starch, ash, sucrose, glucose, fructose, colour, turbidity, and cations (potassium, magnesium, and calcium).

As a second phase to this project, in November 2008, 29 sources of germplasm from five different species of sugarcane, along with a related genus, *Erianthus*, were harvested and analysed.

There were two species, *S. officinarum* and *S. barberi* generally regarded as cultivated species and three generally regarded as wild types, *S. sinense*, *S. spontaneum*, and *S. robustum*.

The stalks were milled by the USDA-SRU in Houma, the juice was put onto ice and immediately transported to the SPRI laboratory for detailed analysis for brix, pH, starch, polysaccharides, ash, colour and turbidity and cations (potassium, magnesium and calcium).

Test procedures, equipment, and references used for the detailed analysis were as follows:

- **pH** – Orion model # 520A meter.
- **Brix** – Bellingham and Stanley RFM81 refractometer.
- **Sucrose, glucose, and fructose** – Liquid Chromatography, BioRad HPX-87K column with 0.01M potassium phosphate (0.6 mL/min at 75°C) RI detection (Waters 2410).
- **Calcium, magnesium, potassium** – Ion Chromatography, Dionex IonPac CS12A column 20 mN H2SO4 at 1 mL/min with Conductivity detection (Dionex ED40)
- **Colour and turbidity** – ICUMSA Method GS1/3-7 (2002) Determination of the Solution Colour of Raw Sugars, Brown Sugars and Coloured Syrups at pH 7.0

**Experimental results**

In the first phase of the project, results of the typical juice analysis performed by the USDA-SRU of the three harvest treatments of three varieties indicated, as expected, that the C treatment (cane free of all extraneous matter) of each variety had the highest sugar content and the lowest fibre content.

The A treatment, consisting of the entire plant, had the lowest level of sugar and highest level of fibre. As expected, the two commercial varieties were not different for comparable harvest treatments, while the wild variety showed significantly lower sugar levels and significantly higher fibre levels.

Results of the detailed juice analysis performed by SPRI of the three harvest treatments of three varieties can be seen in Table 1. The pH ranged from 5.46 to 5.57 with no apparent difference between harvest treatments or varieties.

Varieties Ho95-988 and HoCP96-540 had similar averages in brix content consistent with commercial varieties while L79-1002 had considerably lower brix content.
### Table 1—Detailed analysis conducted by SPRI for three varieties and three harvest treatments for pH, brix, total polysaccharides, starch, ash, colour, turbidity, invert sugars and cations.

<table>
<thead>
<tr>
<th>Sample</th>
<th>pH</th>
<th>Brix</th>
<th>Total polysaccharides</th>
<th>Starch</th>
<th>Ash</th>
<th>Colour</th>
<th>Turbidity</th>
<th>ICUMSA Colour Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>HoCP96-540-A</td>
<td>5.46</td>
<td>19.2</td>
<td>6958</td>
<td>2038</td>
<td>3.27</td>
<td>27</td>
<td>94</td>
<td>272</td>
</tr>
<tr>
<td>Ho95-988-A</td>
<td>5.48</td>
<td>21.0</td>
<td>4954</td>
<td>1984</td>
<td>2.39</td>
<td>18</td>
<td>823</td>
<td>762</td>
</tr>
<tr>
<td>L79-1002-A</td>
<td>5.52</td>
<td>14.3</td>
<td>12 950</td>
<td>5514</td>
<td>10.05</td>
<td>55</td>
<td>201</td>
<td>110</td>
</tr>
<tr>
<td>HoCP96-540-B</td>
<td>5.52</td>
<td>20.4</td>
<td>6078</td>
<td>2372</td>
<td>2.56</td>
<td>16</td>
<td>223</td>
<td>77</td>
</tr>
<tr>
<td>Ho95-988-B</td>
<td>5.48</td>
<td>20.2</td>
<td>5306</td>
<td>2064</td>
<td>2.69</td>
<td>14</td>
<td>512</td>
<td>72</td>
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<tr>
<td>L79-1002-B</td>
<td>5.57</td>
<td>13.5</td>
<td>12 830</td>
<td>5769</td>
<td>10.33</td>
<td>36</td>
<td>694</td>
<td>101</td>
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<tr>
<td>HoCP96-540-C</td>
<td>5.47</td>
<td>20.5</td>
<td>3873</td>
<td>2265</td>
<td>2.10</td>
<td>9656</td>
<td>49</td>
<td>531</td>
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<tr>
<td>Ho95-988-C</td>
<td>5.46</td>
<td>20.4</td>
<td>3919</td>
<td>1620</td>
<td>2.18</td>
<td>11</td>
<td>559</td>
<td>53</td>
</tr>
<tr>
<td>L79-1002-C</td>
<td>5.52</td>
<td>13.4</td>
<td>11 286</td>
<td>6833</td>
<td>10.38</td>
<td>21</td>
<td>949</td>
<td>78</td>
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</table>

<table>
<thead>
<tr>
<th>Sample</th>
<th>Sucrose</th>
<th>Fructose</th>
<th>Glucose</th>
<th>Potassium</th>
<th>Magnesium</th>
<th>Calcium</th>
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</thead>
<tbody>
<tr>
<td>HoCP96-540-A</td>
<td>71.6</td>
<td>8.89</td>
<td>6.54</td>
<td>1.325</td>
<td>0.135</td>
<td>0.180</td>
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<tr>
<td>Ho95-988-A</td>
<td>83.9</td>
<td>8.27</td>
<td>3.27</td>
<td>0.730</td>
<td>0.088</td>
<td>0.106</td>
</tr>
<tr>
<td>L79-1002-A</td>
<td>60.1</td>
<td>10.2</td>
<td>6.40</td>
<td>3.375</td>
<td>0.144</td>
<td>0.305</td>
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<tr>
<td>HoCP96-540-B</td>
<td>81.1</td>
<td>8.31</td>
<td>3.83</td>
<td>0.805</td>
<td>0.092</td>
<td>0.094</td>
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<td>Ho95-988-B</td>
<td>83.8</td>
<td>8.39</td>
<td>3.44</td>
<td>0.805</td>
<td>0.092</td>
<td>0.110</td>
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<td>L79-1002-B</td>
<td>65.5</td>
<td>10.01</td>
<td>5.60</td>
<td>3.210</td>
<td>0.123</td>
<td>0.262</td>
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<tr>
<td>HoCP96-540-C</td>
<td>82.7</td>
<td>1.62</td>
<td>Not detected</td>
<td>0.650</td>
<td>0.068</td>
<td>0.065</td>
</tr>
<tr>
<td>Ho95-988-C</td>
<td>80.1</td>
<td>3.26</td>
<td>3.03</td>
<td>0.665</td>
<td>0.070</td>
<td>0.082</td>
</tr>
<tr>
<td>L79-1002-C</td>
<td>55.5</td>
<td>10.76</td>
<td>8.09</td>
<td>3.905</td>
<td>0.111</td>
<td>0.234</td>
</tr>
</tbody>
</table>

For each variety, treatment C had the lowest level of total polysaccharides with the wild type sugarcane variety L79-1002 having the highest total polysaccharide content. For the starch analysis, there was little difference among harvest treatments, although L79-1002 had much higher starch levels than the two commercial varieties. Differences in ash content were similar to that of total polysaccharides, with the wild type variety considerably higher than the two commercial types.

Juice colour in each harvest treatment was highest for variety L79-1002 as compared to the two commercial varieties. Harvest treatment A (tops, side leaves, and stalk) had the highest colour followed by treatment B. Treatment C, stalks with no leaves or tops, had substantially lower colour regardless of variety. Turbidity followed the same trend as colour.

Varieties HoCP96-540 and Ho95-988 showed comparable sucrose content for harvest treatments B and C, while Ho95-988 was slightly higher in treatment A. Variety L79-1002 had much lower sucrose levels in all three treatments. Variety L79-1002 also reported the highest invert sugar levels of the three varieties, with little difference between the two commercial varieties. Fructose levels were considerably lower in treatment C as compared to treatments A and B for the
commercial varieties, but did not vary in the wild variety. Glucose levels dropped by half from treatments A through C for HoCP96-540, while there was less difference in Ho95-988 and L79-1002.

Cation content varied widely between the three varieties with L79-1002 having the highest levels of potassium, magnesium and calcium as compared to the two commercial varieties. Overall, levels of potassium were higher than levels of the other cations measured.

In the second phase of the project, averages of the analysis of clones of the five different species of sugarcane along with a related genus are shown in Table 2 for the parameters of brix, pH, starch, polysaccharides, ash, colour, turbidity and cations. Large variations in most of the parameters were found between the averages of the different species as well as when comparing clones within the same species. It is very obvious that Erianthus along with clones of the wild species *S. spontaneum* and *S. robustum* were in a much higher range than the cultivated species *S. officinarum*, *S. barberi* and *S. sinense* for several parameters such as polysaccharides, ash content, colour, and to some degree starch and turbidity. Brix was highest for the cultivated species and lowest in the wild clones and *Erianthus*.

**Table 2**—Detailed analysis conducted by SPRI of 29 cultivars among various genera and species of *Saccharum* for pH, brix, total polysaccharides, starch, ash, colour, turbidity invert sugars and cations.

<table>
<thead>
<tr>
<th>Genus/species</th>
<th>pH</th>
<th>Brix</th>
<th>Starch</th>
<th>Total polysaccharides</th>
<th>Ash ppm on solids</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>S. officinarum</em></td>
<td>5.23</td>
<td>17.6</td>
<td>432</td>
<td>1348</td>
<td>6.21</td>
</tr>
<tr>
<td><em>S. barberi</em></td>
<td>5.32</td>
<td>15.9</td>
<td>727</td>
<td>1739</td>
<td>7.98</td>
</tr>
<tr>
<td><em>S. sinense</em></td>
<td>5.40</td>
<td>16.1</td>
<td>374</td>
<td>1898</td>
<td>8.55</td>
</tr>
<tr>
<td><em>S. spontaneum</em></td>
<td>5.33</td>
<td>9.4</td>
<td>2019</td>
<td>5081</td>
<td>30.52</td>
</tr>
<tr>
<td><em>S. robustum</em></td>
<td>5.30</td>
<td>10.8</td>
<td>743</td>
<td>4795</td>
<td>17.04</td>
</tr>
<tr>
<td><em>Erianthus</em></td>
<td>5.30</td>
<td>4.6</td>
<td>2112</td>
<td>21293</td>
<td>23.93</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Genus/species</th>
<th>Colour ICUMSA Colour Units</th>
<th>Turbidity ppm on solids</th>
<th>% Potassium</th>
<th>% Magnesium</th>
<th>% Calcium</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>S. officinarum</em></td>
<td>13 970</td>
<td>44 118</td>
<td>2.20</td>
<td>0.10</td>
<td>0.05</td>
</tr>
<tr>
<td><em>S. barberi</em></td>
<td>12 369</td>
<td>54 545</td>
<td>2.85</td>
<td>0.16</td>
<td>0.13</td>
</tr>
<tr>
<td><em>S. sinense</em></td>
<td>16 037</td>
<td>71 640</td>
<td>2.61</td>
<td>0.21</td>
<td>0.14</td>
</tr>
<tr>
<td><em>S. spontaneum</em></td>
<td>39 356</td>
<td>97 228</td>
<td>11.64</td>
<td>0.36</td>
<td>0.32</td>
</tr>
<tr>
<td><em>S. robustum</em></td>
<td>48 773</td>
<td>98 952</td>
<td>5.83</td>
<td>0.42</td>
<td>0.30</td>
</tr>
<tr>
<td><em>Erianthus</em></td>
<td>138 909</td>
<td>226 107</td>
<td>6.12</td>
<td>0.90</td>
<td>0.95</td>
</tr>
</tbody>
</table>

Of concern is the variation in parameters such as starch content. Domesticated species generally were less than 750, while *S. spontaneum* was 2019 and *Erianthus* was 2112 ppm on solids. Total polysaccharide analysis showed similar variation, although *Erianthus* was higher than all other tested material by a factor of at least 4. Ash content had essentially the same variability with *S. spontaneum* and *Erianthus* being substantially higher. Also of great concern were the average levels of colour for the species.

Averages for the cultivated species were less than 20 000 ICUMSA units, with the wild species higher by a factor of at least 2. *Erianthus* was much higher by a factor of 8 as compared to the cultivated species average. Turbidity showed less distinct differences, although wild species were generally higher than cultivated species and *Erianthus* was considerably higher than all other clones. Results of potassium analysis showed that domesticated species had much lower levels than wild species. The same trend was true for magnesium and calcium although differences were smaller.
To illustrate the amount of variation that existed within species, the individual clones tested of *S. officinarum* and *S. spontaneum* are shown in Table 3 for ash, starch, polysaccharides, potassium, colour and turbidity. As noted in the earlier discussion based on averages, there are considerable differences among the two species in all of these parameters. For ash content and polysaccharides, no clone of *S. spontaneum* was as low as those of *S. officinarum*. However, for starch, potassium, colour and turbidity, even though the averages between species were very different, there were individual clones of *S. spontaneum* that were as low or nearly as low as those of *S. officinarum*.

Table 3—Detailed analysis conducted by SPRI of various cultivars among *S. officinarum* and *S. spontaneum* for total polysaccharides, starch, ash, colour, turbidity and potassium.

<table>
<thead>
<tr>
<th>Clone</th>
<th>Ash %</th>
<th>Starch ppm on solids</th>
<th>Total polysaccharides ppm on solids</th>
<th>Potassium ppm</th>
<th>Colour ICUMSA colour units</th>
<th>Turbidity (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>S. officinarum</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Badilla</td>
<td>3.89</td>
<td>182</td>
<td>1138</td>
<td>1.29</td>
<td>16 084</td>
<td>34 212</td>
</tr>
<tr>
<td>Fiji 1</td>
<td>4.73</td>
<td>315</td>
<td>1258</td>
<td>1.64</td>
<td>11 263</td>
<td>47 106</td>
</tr>
<tr>
<td>Muntok Java</td>
<td>12.85</td>
<td>464</td>
<td>1733</td>
<td>4.82</td>
<td>19 983</td>
<td>54 239</td>
</tr>
<tr>
<td>Green German</td>
<td>4.90</td>
<td>776</td>
<td>1632</td>
<td>1.71</td>
<td>14 044</td>
<td>50 524</td>
</tr>
<tr>
<td>Oi Deng</td>
<td>4.68</td>
<td>421</td>
<td>977</td>
<td>1.55</td>
<td>8476</td>
<td>34 509</td>
</tr>
<tr>
<td>Average</td>
<td>6.21</td>
<td>432</td>
<td>1348</td>
<td>2.20</td>
<td>13 970</td>
<td>44 118</td>
</tr>
<tr>
<td><em>S. spontaneum</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MPTH97-218</td>
<td>23.72</td>
<td>1491</td>
<td>2859</td>
<td>9.12</td>
<td>24 469</td>
<td>75 031</td>
</tr>
<tr>
<td>MPTH97-107</td>
<td>56.08</td>
<td>1530</td>
<td>8345</td>
<td>21.71</td>
<td>106 071</td>
<td>83 055</td>
</tr>
<tr>
<td>MPTH97-216</td>
<td>29.69</td>
<td>1643</td>
<td>5330</td>
<td>11.65</td>
<td>34 649</td>
<td>74 963</td>
</tr>
<tr>
<td>MPTH97-003</td>
<td>37.92</td>
<td>5345</td>
<td>9312</td>
<td>14.40</td>
<td>42 312</td>
<td>109 112</td>
</tr>
<tr>
<td>Tainan</td>
<td>35.13</td>
<td>2001</td>
<td>5245</td>
<td>14.75</td>
<td>55 096</td>
<td>109 489</td>
</tr>
<tr>
<td>Guangzi 87-21</td>
<td>16.50</td>
<td>724</td>
<td>2836</td>
<td>6.14</td>
<td>12 235</td>
<td>89 888</td>
</tr>
<tr>
<td>US 56-15-8</td>
<td>24.01</td>
<td>980</td>
<td>2790</td>
<td>8.56</td>
<td>31 651</td>
<td>106 280</td>
</tr>
<tr>
<td>SES 234B</td>
<td>31.92</td>
<td>3204</td>
<td>6729</td>
<td>10.75</td>
<td>10 003</td>
<td>132 033</td>
</tr>
<tr>
<td>SES 147B</td>
<td>19.69</td>
<td>1256</td>
<td>2286</td>
<td>7.66</td>
<td>37 721</td>
<td>95 200</td>
</tr>
<tr>
<td>Average</td>
<td>30.52</td>
<td>2019</td>
<td>5081</td>
<td>11.64</td>
<td>39 356</td>
<td>97 228</td>
</tr>
</tbody>
</table>

Discussion

Based on the data from the first phase of the project for colour, turbidity, glucose and fructose, it is obvious that leaves and tops contributed negatively to the value of the cane. Based on all of the data, it is also obvious the impact that the wild germplasm has on overall quality with lower sugar content and higher levels of non-sugars and contaminants.

Of value from the data from the second phase is the fact that even within species, there was considerable variation among the clones tested. Whether this is a representative number of clones from each species is unknown and in fact, doubtful. However, it does demonstrate that this variation could allow for selection among the clones for use in breeding energy value canes as well as for routine basic breeding for varieties intended for sugar production or other products.

Based on the knowledge that the level of variability demonstrated in this project may exist among parameters discussed in *Saccharum* and related genera, thoughts should then be directed toward the most efficient breeding of sugarcane for whatever is the desired final product. Knowing that many of the parameters discussed here can have an effect by either enhancing or inhibiting the formation of sugar, ethanol, steam, electricity, and other by-products means that breeders should
begin to take into account the detailed characteristics of elite parents used in their breeding programs. No breeder wants to add another list of parameters to his/her selection criteria, but failing to do so could have severe consequences. Very recently, one sugarcane industry experienced this problem after releasing an outstanding variety for agronomic characteristics only to find out later that some characteristic within the plant did not allow for efficient production of very low colour sugar from this variety. A detailed analysis of this variety before release may have been able to diagnose this problem. It may be that detailed analytical testing could have even prevented the cross from ever having been made or perhaps one of the parents which provided the genes for this characteristic from being used.

As industries continue to look at breeding for products other than sugar, this kind of detailed analysis could become even more important. While it is widely known that factors such as ash content have a negative impact on fermentation, industries are still learning the full impact of starch and polysaccharides on fermentation. These parameters may add fermentable solids, but they can also cause issues in the fermentation process especially related to the activity of the yeast. Cellulosic conversion offers another challenge as to what characteristics would serve as inhibitors or enhancers to efficient energy conversion. Some of the parameters studied here could be considered saleable products and/or precursors to saleable products. Efficient breeding could lead to varieties that are more desirable for each of these potential products.

Biotechnology and gene transformation could perform a very important role in altering the components of sugarcane for more efficient production of final products. Equally important is the potential for sugarcane genome sequencing. Also important is the development of markers associated with these juice characteristics. These technologies could allow for the identification of the genetic basis for these compositional characteristics.

When considering the use of varieties, knowledge of these detailed analyses could lead to more sustainable production practices. Growers often fertilise sugarcane to produce the highest yield of sugarcane believing that this will lead to the highest yield of sugar, as it often does. However, variation in cations among the germplasm studied here would suggest that not all cane is alike. Whether there are different absorption rates by species is not understood but further studies could lead to more efficient utilisation of varieties, especially when considering sustainable production practices where one attempts to utilise minimal inputs to arrive at maximum yield. Water utilisation and the significance of clean ground water for the future could be impacted through a better understanding of the role of the parameters discussed in this paper. The impact of some of these parameters on pest management should also receive consideration.

Processing of varieties has always used the ‘average’ approach where an industry sets its objectives, and varieties are expected to fall into that range or else the variety is not released to that industry. These parameters are generally based on efficient production of sugar, which of course is still the highest value product that most industries can produce. However, as industries examine the production of other products, these ‘average’ levels of various parameters may need to be reconsidered. As alternative products are planned, different separation technologies may need to be considered in order to efficiently produce these materials.

During this current period of unusually high world prices of sugar, is anybody really interested in producing products other than sugar? Perhaps the level of interest or desire is not as great as when sugar prices were low and industries were struggling to survive. However, a good strategist would argue that now is the time to think about these issues, out of a position of strength and high sugar prices rather than one of weakness and low sugar prices!

Future work with detailed analysis should include more detailed fibre analysis for cellulose, hemicellulose, and lignin content for their contribution to the value of the sugarcane plant. Also a more in-depth chromatographic analysis for cations, anions, oligosaccharides, sugars, and organic
acids should be considered. Additionally, the same issues should be investigated in sugarbeets as well as sugarcane.

Acknowledgements

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REFERENCES


CONCEVOIR, PRODUIRE ET TRAITER LES VARIETES DE CANNE A SUCRE DU FUTUR

Par

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MOTS-CLÉS: Variétés De Canne à Sucre, Amélioration Variétale, Composition de la Canne, Analyse Chromatographique, Produits Alternatifs.

Résumé

DE NOMBREUSES industries sucrières, de betterave ou de canne, font la prédiction qu’elles produiraient dans le futur une vaste gamme de produits, incluant le sucre. Pour réaliser cette prédiction, de nouvelles variétés doivent être conçues, passant par une amélioration des pratiques culturales et un développement des techniques de process. La sélection et l’amélioration variétale ont progressé bien au delà des méthodes anciennes de croisement des parents avec l’espoir de sélectionner la meilleure ségrégation qui aboutissant à une nouvelle variété potentielle. Les procédures modernes de création associée à la biotechnologie offre une plus grande efficience. De façon typique, les variétés sont sélectionnées sur la base d’un haut rendement en sucre et des caractéristiques agronomiques pour la production et la résistance aux ravageurs dans chacune des zones de production. Les habituelles caractéristiques de qualité mesurées du jus - Brix et Pol - ainsi que le tonnage, le comportement en repousse et le taux de fibre, peuvent prédire le rendement en sucre par unité de surface. Il est appréhendé que l’ultime variété du futur implique davantage d’analyses détaillées que les habituelles caractéristiques mesurées. Une fois créées, les variétés à haut rendement en produits variés devront être cultivées de façon durable tout en procurant le maximum de production avec un impact environnemental et économique minimum. Le traitement de ces variétés imposera d’adapter le ou les produits spécifiques en cours d’élaboration que ce soit pour le sucre, l’énergie, d’autres produits ou des combinaisons de ceux-ci. Pour démontrer l’importance des caractéristiques de qualité des futures variétés L’institut de Recherche du Process Sucrerie a investigué la présence de composés qui pourraient soit augmenter ou inhiber la production de produits variés issus de la canne à sucre. Des variabilités significatives parmi les espèces de canne à sucre et des genres proches ont été trouvées pour l’amidon, les polysaccharides, les cendres, les cations, les sucre inversés et d’autres paramètres. Cet article présente ces données et l’importance potentielle de ces paramètres dans les futures variétés, leur importance dans un système de production durable et son importance dans les besoins de process technologique.
DISEÑO, PRODUCCIÓN Y PROCESAMIENTO DE VARIEDADES ‘SUPREMAS’ DE CAÑA DE AZÚCAR

Por

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PALABRAS CLAVE: Variedades de Caña de Azúcar, Mejoramiento de Caña de Azúcar, Composición de la Caña de Azúcar, Análisis Cromatográfico, Productos Alternativos.

Resumen
MUCHAS industrias azucareras, de remolacha y caña, podrían predecir que en el futuro producirán una amplia variedad de productos, entre ellos azúcar. Para realizar esta predicción, se debe diseñar nuevas variedades de caña, mejorar las prácticas de producción y desarrollar nuevas técnicas de procesamiento. El mejoramiento y la selección de la caña de azúcar han evolucionado mucho desde los ‘viejos tiempos’ en que se hacían cruzas de los mejores progenitores y se esperaba seleccionar los mejores segregantes como potenciales nuevas variedades. Los procedimientos modernos de mejoramiento y la biotecnología ofrecen una mayor eficiencia. Generalmente, las variedades se seleccionan con base en alta productividad de azúcar y algunas características agronómicas importantes para la producción, además de la resistencia a plagas en cada región. Las características del jugo comúnmente medidas de Brix y pol, además del tonelaje, habilidad de soqueo y contenido de azúcar, permiten predecir el rendimiento de azúcar por unidad de área. Se prevé que la variedad ‘suprema’ del futuro implicará un análisis mucho más detallado de las características que se miden de rutina. Una vez producidas, las variedades de alto rendimiento para varios productos, necesitan ser cultivadas de una forma sostenible que proporcione la máxima producción con un mínimo impacto ambiental y económico. El procesamiento de estas variedades deberá acomodarse a los diferentes productos que se obtendrán ya sean azúcar, energía, otros productos o combinación de estos. Para demostrar la importancia de las características de calidad de las variedades del futuro, el Instituto de Investigación del Procesamiento de Azúcar ha investigado la presencia de componentes que podrían mejorar o inhibir la obtención de varios productos de la caña de azúcar. Se ha encontrado variabilidad significativa tanto inter, como intraespecífica en caña de azúcar y géneros relacionados, en cuanto a contenidos de almidón, polisacáridos, cenizas, cationes, azúcares invertidos y otros parámetros. Este trabajo incluye estos datos y la importancia potencial de estos parámetros en variedades futuras, su importancia en un sistema de producción sostenible y en las necesidades de procesamiento.
EVALUATING SUGARCANE R&D PERFORMANCE:
EVALUATION OF THREE BREEDING PROGRAMS

By

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KEYWORDS: R&D Performance, Benchmarking,
Technology Valuation, Technology Adoption.

Abstract

RESOURCES for sugarcane R&D are scarce, as they are for most agricultural R&D, and investors in R&D want a return on their investment in the form of productivity and profitability gains that arise from the adoption of new technologies. These realities motivate productive and efficient R&D programs that are a key driver of ongoing productivity improvement in sugarcane industries. Sound technical programs deliver ongoing industry benefits sustaining industry profitability and underpinning industry growth. In the context of these R&D programs, strategic and tactical decisions made during the management of R&D projects are vitally important with respect to the outcomes delivered by R&D, and their subsequent uptake by industry. We illustrate these principles using variety performance data from Australia, Brazil and South Africa. Our findings include evidence for rapid uptake of new varieties, significant improvements in yield of cane per hectare and financial benefits delivered to growers adopting these improved cane varieties. Differences existed between the R&D programs in terms of the benefits being delivered to the respective industries that could be directly connected with particular research strategies employed. R&D is an investment, not a cost, but it becomes a cost if benefits are not realised by industry.

Introduction

We undertook a study to quantify benefits being delivered to sugarcane industries in Australia (only Queensland), Brazil and South Africa by the breeding aspects of research, development and extension (RD&E) programs undertaken by BSES Limited (BSES), Centro de Tecnologia Canavieira (CTC) and the South African Sugarcane Research Institute (SASRI). The rationale for the study was as follows: investors in sugarcane research, growers, millers, governments and others, want a return on their investment. This return can be measured by the rate of uptake of new technologies and enhanced returns in the investors’ businesses following the adoption of these new technologies. In the case of our institutions, the investors are also the customers for the services, new products and technologies developed by our RD&E programs. This brings into sharp focus the performance of the technologies in the hands of our customers and the return on investment to the growers, millers and others that support our programs.

In the Australian case, growers and millers interpret the plateau in industry outputs with respect to sugar yield as a failure of the R&D programs to deliver new technologies that enhance industry performance (Figure 1). This is despite comprehensive analyses (Cox and Stringer, 2007) that support the proposition that significant rates of genetic improvement are being achieved and, indeed, that the rate of genetic improvement is increasing.
This contradiction should not be surprising. Agricultural systems are complex, and dissection of cause and effect with respect to the contribution being made by R&D to improved agricultural performance is not well developed.

Wynne and Gilmour (these Proceedings) consider first some financial metrics that can be used to estimate the performance of investments in agricultural R&D and, secondly, the relative merits of different benchmarking methods for assessing R&D performance.

A central tenet of their analyses is that broad industry statistics, such as illustrated in Figure 1, can not directly be used to evaluate RD&E performance. In short, if:

\[ P = G + E + M; \]

where

- \( P \) = a measure of crop performance (e.g. tonnes sugar per hectare); and
- \( G \) = an estimate of the genetic effect;
- \( E \) = an estimate of the environmental effect; and
- \( M \) = an estimate of the crop management effect (including the interaction effects between \( G \) and \( E \)); then

inferences about neither \( G \), nor \( E \), nor \( M \) can be made by simply measuring and interpreting \( P \).

More analytical work is required to dissect out the contribution being made by each effect and to better value how each have contributed to lowering input costs or increasing productivity.

Our study deliberately concentrates on dissecting out the value contributed to productivity improvements by genetic improvement. This is motivated by availability of data sets to perform a range of analyses relevant to objectively evaluate the value being created by genetic improvement programs being undertaken by our institutions.

Schroeder et al. (2009) have considered aspects of the contribution being made by farming systems to improved industry performance, but such considerations are not examined here.
The audiences for the studies we have undertaken are the Boards and Senior Management of our respective organisations, together with the growers, millers and other investors in the industries we serve. The study is a snapshot of some aspects of the performance of our R&D programs. The results for each program provide a relative reference point against which others can be assessed. It does not follow that a particular program should be judged superior to any other.

There is a strong temptation to make direct comparisons, but such interpretation is flawed since the strategic rationale that underpins each program is quite different. The results are specific to the settings in which each RD&E program is operating, and direct comparisons between programs should be avoided.

For example, if the research strategies and operations of BSES were transferred to Brazil, it does not follow that the same performance as is achieved in Australia will be evident in Brazil. Similarly, if the research strategies and operations of CTC are transferred to South Africa, it does not mean that results equivalent to those in Brazil will be realised.

Nevertheless, the relative performance provides an important benchmark against which the progress of each RD&E program can be assessed.

Materials and methods

Terminology

Because sugar content of cane is measured in different ways in each country, throughout the text we simply use the terms sugar content (SC), tonnes of sugar (TS) and tonnes of sugarcane per hectare (TSH) as substitutes for the country-specific measures of sugar content: CCS (Queensland), ATR (Brazil) and ERC (South Africa) unless there is a specific need to identify a specific measure. In all data presentations in tables and graphs, we specifically indicate the appropriate measure.

Data

Three data sets were compiled for each of Queensland, Brazil and South Africa to compare and contrast: (1) basic industry statistics; (2) variety adoption trends and (3) rates of genetic gain and value to growers and millers as a result of developing and releasing genetically improved varieties.

The industry statistics data set was historical industry data for 1996–2006 (inclusive) for tonnes of cane (TC) and sugar (TS) produced, and tonnes of cane (TCH) and sugar (TSH) per hectare.

The variety adoption data set was historical industry data for the tonnes of cane delivered of specific varieties to mills for Queensland (1970–2007), Brazil (1984–2007) and South Africa (1979–2007).

For Queensland (1970–2007) and Brazil (1998–2007), the data sets for estimating rate of genetic gain included data for the tonnes of cane delivered to mills of specific varieties, the sugar content of those varieties reported either as commercial cane sugar (CCS, Queensland) or total recoverable sugar (ATR, Brazil) and the number of hectares on which varieties were grown to derive TCH and TSH on an individual variety basis.

For South Africa, data were not available for the number of hectares on which individual varieties were grown, which precluded estimation of rates of genetic advance being made by sugarcane breeding using industry data. As a substitute, we used data from the SASRI variety improvement research program. The data set comprised yield data and estimated recoverable crystal / ha (t ERC/ha) for each released variety during the period 1980 – 2007.

Analytical methods

Industry production trends were examined for each country by plotting TCH and TSH over time. Variety adoption trends were examined by plotting percentage area planted to specific varieties over time. We calculated average duration in production (last year in commercial production—first year in commercial production) over all varieties, and examined the dominance of
varieties by grouping varieties into categories according to the area they occupied in commercial production. For Queensland and Brazil, we calculated a weighted average age of varieties in commercial production over time using % area planted data where:

\[ \text{Age}_i = \frac{\sum_{j=1}^{n} (C_j \times A_{ij})}{n_i} \]

where:

- \( \text{Age}_i \) = Average age of varieties in year \( i \);
- \( P_i \) = Year of production, where \( i = 1984, \ldots, 2007 \);
- \( C_j \) = Year of cross (Brazil) or year of first seedling in trials (Queensland) for variety \( j \);
- \( A_{ij} \) = Percent area planted in year \( i \) to variety \( j \);
- \( n_i \) = Number of varieties in commercial production (i.e. \( A_{ij} > 0.0\% \)) in year \( i \).

For calculating rates of genetic advance, we followed Cox et al. (2005). Briefly, this entailed the following steps. For Queensland and Brazil, where data were available for the number of hectares planted to each commercial variety, the area planted was weighted by its cube root. This has the effect of reducing the emphasis of new varieties recently in commercial production and planted to only small areas. TCH and TSH were then estimated as best linear unbiased predictors (BLUP) by fitting a mixed linear model with varieties as random effects using the software package ASREML (Gilmour, 1999). Average rates of gain over the study period were calculated by fitting a linear regression to the relationship: TCH or TSH versus year of variety release into commercial production. Rates of genetic advance were estimated for Q varieties originating from the BSES-CSIRO breeding program in Queensland, for SP and RB varieties originating from the Copersucar / CTC, and RIDESA breeding programs respectively in Brazil, and for N and NCo varieties originating from the SASRI breeding program in South Africa.

Thus:

The average rate of genetic improvement of all varieties was calculated as:

\[ \Delta G = \frac{n \times \sum_{i=1}^{n} (y_i \times v_i) - \sum_{i=1}^{n} y_i \times \sum_{i=1}^{n} v_i}{n \times \sum_{i=1}^{n} (y_i^2) - (\sum_{i=1}^{n} y_i)^2} \]

where:

- \( \Delta G \) = Average rate of genetic advance for all varieties;
- \( n \) = the number of varieties;
- \( y_i \) = Year of release of variety \( i \), where \( i = 1, \ldots, n \); and
- \( v_i \) = BLUP of the performance of variety \( i \).

The value of varieties in commercial production was calculated assuming a financial model for the performance of a hypothetical 100 ha farming enterprise as generally set out in Table 1.

**Table 1**—Financial model for calculating the value of new varieties in commercial production.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Farm using base (B) varieties</th>
<th>Farm using improved (I) varieties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenue</td>
<td>( R(B) = 100*\text{TCH}(B)\times\text{SC}(B)\times\text{SP} )</td>
<td>( R(I) = 100*\text{TCH}(I)\times\text{SC}(I)\times\text{SP} )</td>
</tr>
<tr>
<td>Expenditure</td>
<td>( E(B) = 100*\text{TCH}(B)\times\text{PC}(B) )</td>
<td>( E(I) = 100*\text{TCH}(I)\times\text{PC}(I) )</td>
</tr>
<tr>
<td>Earnings before interest and tax (EBIT)</td>
<td>( \text{EBIT}(B) = R(B) - E(B) )</td>
<td>( \text{EBIT}(I) = R(I) - E(I) )</td>
</tr>
<tr>
<td>Benefit of improved varieties ($/ha)</td>
<td>((\text{EBIT}(I) - \text{EBIT}(B))/100)</td>
<td></td>
</tr>
</tbody>
</table>
where:

Hypothetical farm size = 100 ha
TCH=Average yield on farm of either base (B) or improved (I) varieties;
SC=Average sugar content on farm of either base (B) or improved (I) varieties;
SP=Sugar price, assumed to be US$300/tonne
PC=Average production cost per hectare of hypothetical farm growing base (B) or improved varieties (I)

The following base assumptions were used for all three countries:

- Average grower production cost = US$20 / t cane
- Harvest and transport cost = US$6.50 / t cane
- Miller crushing cost = US$15 / t cane
- Sugar price = US$300 / t sugar

In addition, the following country-specific assumptions were made:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Queensland</th>
<th>Brazil</th>
<th>South Africa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base germplasm</td>
<td>&lt; 1996 smut susceptible</td>
<td>&lt; 1996</td>
<td>&lt; 1996</td>
</tr>
<tr>
<td>Improved germplasm</td>
<td>&gt;= 1996 smut resistant</td>
<td>&gt;=1996</td>
<td>&gt;=1996</td>
</tr>
<tr>
<td>Cane production</td>
<td>32 Mt</td>
<td>309 Mt</td>
<td>20 Mt</td>
</tr>
<tr>
<td>TCH base</td>
<td>96.6</td>
<td>90.4</td>
<td>99.5</td>
</tr>
<tr>
<td>TCH improved</td>
<td>103.8</td>
<td>94.5</td>
<td>101.7</td>
</tr>
<tr>
<td>SC base</td>
<td>13.5</td>
<td>14.2</td>
<td>13.4</td>
</tr>
<tr>
<td>SC improved</td>
<td>14.1</td>
<td>13.9</td>
<td>13.9</td>
</tr>
</tbody>
</table>

The benefit estimates were used to determine reasonable fees that could be charged of growers and millers on the following basis:

- Proportion of EBIT benefit retained by growing and milling sectors (W) = 80%;
- Proportion of EBIT benefit retained by breeding organisation (X) = 100–W = 20%.

Then:

- Apportionment of EBIT benefit share to breeding organisation as a grower fee (G) = 64%*X;
- Apportionment of EBIT benefit share to breeding organisation as a miller fee (M) = 36%*X.

The revenue stream due to each breeding organisation was then calculated using the respective cane production base for each organisation such that:

- Revenue (BSES) = (GB+MB)*32*10^6;
- Revenue (CTC) = (GC+MC)*309*10^6;
- Revenue (SASRI) = (GS+MS)*20*10^6.

Where the subscripts, B, C and S, refer to the respective breeding organisations: BSES, CTC and SASRI.

**Results and discussion**

**Industry production trends**

The results for the annual trend in tonnes of cane production per hectare over the period 1996 to 2006 (Figure 2) indicate that there has been an increase in productivity of 0.68 TCH in Brazil, and a decline in South Africa of 0.43 TCH. In Queensland, average productivity is higher than in either Brazil or South Africa, but the average is more volatile connected with weather events (too wet and too dry) and disease (illustrated by the 1999–2000 orange rust epidemic).
Average, industry-wide sucrose content in both Brazil and South Africa has increased from 1996 to 2006, although the relationship for South Africa is weaker than that for Brazil (Figure 3). For Queensland, sucrose content has been volatile.
For TSH, the results follow the tonnes of cane per hectare results with Brazil having an annual increase in average tonnes of sugar per hectare of 0.14 TSH/year whereas, for South Africa, there has been a decline in average TSH by 0.08 TSH/year (Figure 4). For Queensland, TSH has been higher than both Brazil and South Africa. However, it has also been volatile and declined by an average of 0.05 TSH/year over the period.

Variety adoption trends

The variety adoption trend data for Queensland (Figure 5) indicate that varieties typically have a commercial production life of approximately 20 years comprising four five-year crop cycles. There is no distinct evidence of the duration of varieties in commercial production changing over the 37-year period from 1970 to 2007.
For Brazil (Figure 6), average duration of varieties in commercial production is approximately 15 years and, like in Queensland, there is no evidence that this has changed significantly from 1984 to 2007. The data are consistent with varieties being grown for three crop cycles using a system of a plant crop and four ratoons.

In South Africa (Figure 7), the variety composition plots are dominated by two varieties NCo376 and N12. The data suggest that varieties have a very long life in commercial production, exceeding 25 years in some cases. This is consistent with the long crop cycles ranging from two to four cycles of plant crops and 7–10 ratoons.
The average crop age results illustrate the domination of the Queensland crop through the late 1990s by the variety Q124, followed by the disadoption of that variety following a race change in the orange rust population (Figure 8). In Brazil, there is evidence for average crop age increasing. This probably reflects a preference to plant older varieties in new production areas because of the availability of seed cane and the known performance characteristics of those varieties.

Fig. 8—Weighted average crop age for Queensland and Brazil.

There have been marked differences between Queensland, Brazil and South Africa in the uptake of PBR-protected varieties (Figure 9). The data indicate that uptake in Queensland was, initially, slower than in Brazil, but that since about 2003, the rate of uptake in Queensland has greatly surpassed the rate of uptake of Brazilian PBR protected varieties. Generally, the uptake of new varieties in South Africa has been very slow, mainly due to the traditionally long crop cycles (Figure 6c, see below).

Fig. 9—Rate of uptake of PBR-protected varieties in Queensland, Brazil and South Africa.
The annual average rate of genetic gain for TCH, SC and TS (Table 2) indicates that there has been significant genetic advance for TCH by varieties from the SP program and to a lesser extent, the RB program. For TCH, the Q program has had a similar rate of genetic gain to the RB program in Brazil. For South Africa, there are four subprograms that had markedly different rates of genetic advance for TCH ranging from 1.18 TCH/year for CS12 (Coastal, 12 month harvesting cycle) to 0.06 TCH for CS18 (Coastal, 18 month harvesting cycle). For SC, the data indicate improvement for Q varieties, but neutral to slightly negative progress for SP and RB varieties. For South African varieties, there are variable results for SC ranging from 0.05%/year improvement in MD24 (Midlands, 24 month harvesting cycle) to –0.08%/year regression in CS12.

The key outcome from these results is that results for improvement of TS/year were equal for varieties from the SP and Q programs (0.281 TSH/year), with modest gains also being made by the RB program. Small genetic gains were made by varieties from the South African subprograms ranging from 0.015 TSH for CS18 to 0.081 TSH for MD24. It is important to note here that the extent and nature of the data used for the analyses varied considerably from country to country. Consequently, it was difficult to make fair comparisons between countries. Further, the South African sugar industry is unique in that there are four sub-programs where selection occurs to meet the requirements for the variable agro-climatic regions. These main agro-climatic regions include the Northern Irrigated region (NI12) where the sugarcane is irrigated and harvested at 12 months of age, the Coastal long cutting cycle region (CS18) where the cane is rainfed and harvested at 18 months of age, the Coastal short cutting cycle region (CS12) where cane is rainfed and harvested at 12 months of age and then the Midlands region (MD24) where cane is rainfed and harvested at 24 months of age.

Table 2—Rate of genetic gain for tonnes of cane per hectare, sugar content and tonnes of sugar per hectare for Queensland (Q), Brazil (SP, RB) and South Africa (CS12, CS18, NI12, MD24).

<table>
<thead>
<tr>
<th>Data set</th>
<th>ΔTCH/yr</th>
<th>ΔSC/yr</th>
<th>ΔTS/yr</th>
<th>ΔTC/TS/yr</th>
<th>Start</th>
<th>End</th>
<th>No years</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS12</td>
<td>1.18</td>
<td>–0.08</td>
<td>0.070</td>
<td>0.06</td>
<td>1997</td>
<td>2007</td>
<td>10</td>
</tr>
<tr>
<td>CS18</td>
<td>0.06</td>
<td>0.01</td>
<td>0.015</td>
<td>–0.01</td>
<td>1997</td>
<td>2007</td>
<td>25</td>
</tr>
<tr>
<td>NI12</td>
<td>0.82</td>
<td>–0.03</td>
<td>0.050</td>
<td>0.03</td>
<td>1997</td>
<td>2007</td>
<td>10</td>
</tr>
<tr>
<td>MD24</td>
<td>0.17</td>
<td>0.05</td>
<td>0.081</td>
<td>–0.04</td>
<td>1997</td>
<td>2007</td>
<td>10</td>
</tr>
<tr>
<td>SP</td>
<td>2.13</td>
<td>–0.01</td>
<td>0.281</td>
<td>0.01</td>
<td>1983</td>
<td>2002</td>
<td>19</td>
</tr>
<tr>
<td>RB</td>
<td>1.17</td>
<td>–0.02</td>
<td>0.149</td>
<td>0.01</td>
<td>1989</td>
<td>2002</td>
<td>13</td>
</tr>
<tr>
<td>Q</td>
<td>1.33</td>
<td>0.04</td>
<td>0.281</td>
<td>–0.08</td>
<td>1983</td>
<td>2006</td>
<td>23</td>
</tr>
</tbody>
</table>

These results are supported by Figures 10, 11 and 12, which show the nature of the relationship between TCH and SC for varieties released by each of the programs over the period of study. In the case of Q varieties, the data indicate simultaneous improvement of both TCH and SC (Figure 10). For the SP and RB programs in Brazil (Figure 11), the data indicate that there has been a tremendous improvement in TCH over the period of study while Pol% has been held in a narrow range without achieving a significant SC improvement in new high yielding varieties.

For South Africa (Figure 12), the data clearly indicate a strong negative correlation between TCH and SC, suggesting that improvement is being made in SC of new varieties, albeit at the expense of TCH. We believe that this may be because the South African varieties have a significantly greater contribution of *Saccharum spontaneum*, which contributes to the higher stalk populations and good ratooning ability of sugarcane varieties and which makes joint improvement of both TCH and SC difficult. It is likely that increased selection pressure for higher quality and sucrose content has been at the expense of selecting for higher cane yield.
Fig. 10—Relationship between tonnes of cane per hectare (TCH) and Pol% for varieties released in Queensland by the BSES-CSIRO breeding programs from 1962 to 2006.

Fig. 11—Relationship between tonnes of cane per hectare (TCH) and Pol% for varieties released in Brazil by the Copersucar/CTC (1983–2001) and RIDESA (1989–2001) breeding programs.
Fig. 12—Relationship between tonnes of cane per hectare (TCH) and Pol% for varieties released in South Africa by the SASRI breeding programs from 1955 to 2008.

Value of varieties in commercial production

The results summarising reasonable fees that each breeding organisation could charge on the basis that 20% of the EBIT benefit delivered by those varieties is captured by the breeding organisation are shown in Table 3.

Table 3—Summary of fees that could be reasonably charged assuming 20% of the EBIT value is captured by the breeding organisation. (Currency values are US dollars).

<table>
<thead>
<tr>
<th>Institution</th>
<th>TCH benefit</th>
<th>SC benefit (%)</th>
<th>Grower fee ($/t)</th>
<th>Miller fee ($/t)</th>
<th>Total fee ($/t)</th>
<th>Annual revenue ($m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSES</td>
<td>16.5</td>
<td>0.4</td>
<td>0.88</td>
<td>0.35</td>
<td>1.23</td>
<td>43</td>
</tr>
<tr>
<td>CTC</td>
<td>4.1</td>
<td>-0.3</td>
<td>0.16</td>
<td>0.09</td>
<td>0.25</td>
<td>77</td>
</tr>
<tr>
<td>SASRI</td>
<td>2.2</td>
<td>0.5</td>
<td>0.18</td>
<td>0.10</td>
<td>0.28</td>
<td>6</td>
</tr>
</tbody>
</table>

The results indicate that each organisation is delivering significant value to the respective industries they serve through variety improvement alone, relative to fees currently being paid by organisation members. We estimated that reasonable fees ranged from $0.25/tonne of cane for CTC to $1.23/tonne of cane for BSES. If such fees were implemented, reasonable revenue streams could be generated by each organisation ranging from $6m per annum for SASRI to $77m per annum for CTC.

We emphasise that it is not the purpose of this paper to set out fees that our respective organisations could reasonably charge industry members for accessing research services. Many factors other than the research organisation capturing a proportion of the value delivered will impact on decisions to set fees at a particular level. The methodology set out here can be used to inform that decision in an objective way. This proposition is reasonable under the assumption that the technology, in this case, new varieties, is adopted commercially.
Conclusions

In this paper, we have set out a range of data that provide an insight into the performance of our respective research organisations with respect to the value being delivered to the sugarcane industries we serve. We chose to focus on variety improvement because of the availability of data for such a study and the ability to design an objective framework for estimating the impact of those varieties in commercial production, namely adoption of new varieties, rates of genetic advance and value delivered by new varieties in commercial production.

The study has illustrated that value is being delivered to the industries we serve by our respective organisations. There are clear differences between organisations in the quantum of value delivered, and in the rate of uptake of new varieties. It would be incorrect to conclude that these differences are a function solely of differences between the organisations. Each organisation operates in relation to specific resources to meet the strategic needs of their respective industries and into which new technologies are delivered for commercial production. What the study has done is demonstrate that research strategy and industry setting can have a major impact on realising the value being delivered by research investments. This is clearly illustrated by the contrasts with respect to joint improvement of TCH and SC, and the marked differences in the rate of uptake of new varieties.

The study was proposed by the respective Chief Executives of our organisations as an opportunity to benchmark the performance of each organisation against one another. We conclude that the study has been somewhat useful for this purpose. In the future, the approach could usefully be extended to relevant comparisons in other research areas, particularly the performance of farming systems research programs and the effectiveness of extension programs.

Acknowledgements

This study was initiated by Eoin Wallis, Nilson Boeta and Frikkie Botha. We thank Dr Joanne Stringer for the BLUP analyses. The germplasm valuation framework was developed by Brian Carrick and Andrew Wellington. The following assisted by providing data and advice regarding analytical methods and interpretation of the results: in Australia: Barry Callow, Michael Cox, Eve McDonald, James Ogden-Brown, Joanne Stringer, Xianming Wei and Trevor Willcox; in Brazil: Tadeu Andrade, Michel Choairy, Mauricio Antonio de Oliveira, Jose Perez Rodrigues Filho, Luiz Antonio Dias Paes, Adhair Ricci; and in South Africa: Carolyn Baker, Mike Butterfield, Steve Davis, Charles Dettman, Chris Gillett, Rod Harding, Aresti Paraskevopoulos and Adrian Wynne.

REFERENCES


EVALUER LA PERFORMANCE DE LA R&D CANNE A SUCRE: COMPARAISON DE ROIS PROGRAMMES DE SELECTION

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MOTS-CLES: Performance de la R&D, Étalonnage Concurrentiel, Évaluation Technologique, Adoption de la Technologie.

Résumé

LES RESSOURCES pour la R&D en canne à sucre sont rares, car elles sont principalement pour la R&D agricole et les investisseurs en R&D veulent un retour sur leur investissement en termes de gains de productivité et profitabilité liées à l’adoption de nouvelles technologies. Ces réalités stimulent la mise en œuvre de programmes R&D productifs et efficients qui sont un élément moteur pour la l’amélioration continuelle de la productivité dans les industries de canne à sucre. Les programmes techniques bien adaptés apportent des bénéfices industriels permanents soutenant la profitabilité de l’industrie ainsi que sa croissance. Dans le contexte de ces programmes R&D, les décisions stratégiques et tactiques prises durant la gestion des projets R&D sont d’une importance vitale pour les produits et résultats fournis par la R&D et leur adoption par l’industrie. Nous illustrons ces principes en utilisant des données de performance des variétés en Australie, Brésil et Afrique du Sud. Nos conclusions inclus l’évidence pour une adoption rapide de ces nouvelles variétés, des améliorations significatives de rendements en canne par hectare et des bénéfices financiers pour les planteurs adoptant ces variétés de canne améliorées. Des différences existent entre les programmes R&D en termes de bénéfices à fournir aux industries respectives qui pourraient être directement connectées à des stratégies de recherche particulières. La R&D est un investissement et non un coût, mais elle devient un coût si les bénéfices ne sont pas réalisés par l’industrie.
EVALUACIÓN DEL DESEMPEÑO DE LA INVESTIGACIÓN Y DESARROLLO EN CAÑA DE AZÚCAR: COMPARACIÓN DE TRES PROGRAMAS DE MEJORAMIENTO

Por

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PALABRAS CLAVE: Desempeño de la Investigación y Desarrollo (R&D), Benchmarking, Evaluación de Tecnología, Adopción de Tecnología.

Resumen

Los recursos para realizar investigación y desarrollo (I+D) en caña de azúcar son escasos, como generalmente ocurre en el área agrícola, y los inversionistas en I+D, esperan un retorno de sus inversiones en forma de mejoras en la productividad y ganancias que deriven de la adopción de nuevas tecnologías. Estas realidades, motivan a los programas de I+D a ser productivos y eficientes y los convierten en motores clave para las mejoras en productividad que se dan en las industrias azucareras. Programas técnicos sólidos resultan en beneficios constantes que mantienen la rentabilidad de la industria y ayudan a su crecimiento. En el contexto de estos programas de Investigación y Desarrollo, las decisiones tácticas y estratégicas que se tomen durante la gestión de los proyectos de I+D son de vital importancia con respecto a los resultados obtenidos y su adopción por parte de la industria. Nosotros ilustramos estos principios usando datos del desempeño de variedades en Australia, Brasil y Sudáfrica. Nuestros resultados incluyen evidencia de la rápida adopción de las nuevas variedades, mejoras significativas en el rendimiento de la caña por hectárea y beneficios financieros que obtuvieron los productores que adoptaron estas variedades mejoradas de caña. Se determinó que hay diferencias entre los programas de I+D en términos de los beneficios que se para a las industrias respectivas y que podrían estar relacionados con el uso de estrategias de investigación particulares. I+D es una inversión, no un costo, pero se convierte en costo, si los beneficios no son conocidos por la industria.
SUSTAINABILITY AND THE AUSTRALIAN SUGAR INDUSTRY

By

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KEYWORDS: Australia, Sustainability, Legislation.

Abstract

This paper reviews the legislative, environmental and social requirements faced by the Australian sugar industry. It concludes that the Australian industry probably operates under more environmental scrutiny and control than most, has less government protection than most but suffers less interference in its commercial arrangements than most.

Introduction

The sugar industry in Australia is among the world’s largest exporters of raw sugar, but internally its sugar industry is relatively small. Sugar contributes 4% to the gross value of agriculture in Australia and agriculture in turn makes up 4% of the country’s GDP. The sugar industry is scattered along the Queensland and Northern New South Wales coast and, despite its size in the overall economy, is the vital economic lifeblood of many towns and regions.

It could be described as capital rather than labour intensive, compared to many industries worldwide. Around 3800 cane growing enterprises supplying ten milling companies produce between 30 Mt and 35 Mt cane and 4.5–5 Mt sugar. The industry is close to the iconic Great Barrier Reef and several major centres of urban expansion.

Legislative

Sugar producers in Australia have no market or tariff protection; the industry competes with other sugar producing countries on the world stage and domestically. Apart from small US and EU quotas, it has no preferential markets. Specific sugar legislation is minimal and growers and millers make contracts commercially, without resort to external arbitration. There is no national ethanol mandate, but the state of New South Wales has a 2% requirement in place and Queensland has announced a 5% mandate. A national Renewable Energy Target of 20% of stationary energy by 2020, introduced in 2009, will give an impetus to cogeneration in sugar mills.

Sugar industry participants, as individuals and corporations, are bound by a substantial amount of Australian and state legislation, much of which has a strong focus on environment protection (summarised in Appendix 1).

In particular, the Environmental Protection Act 1994 establishes a general duty of care, which means growers need to take all reasonable and practical measures to minimise the risk of harm to the environment. New legislation to limit fertiliser and pesticide output from the sugar and grazing industries in the catchment of the Great Barrier Reef has recently been passed by the Queensland Parliament.

All affected farmers in these catchments, which account for over 70% of production, will be required to keep comprehensive records of their use of agricultural chemicals, fertilisers, soil conditioners and soil testing results, apply no more than the optimum level of fertiliser, and observe new restrictions on the use of some agricultural chemicals.
The industry’s social obligations require compliance with general workplace health and safety regulations and the *Trade Practices Act 1974* which regulates business activities.

Australia ratified the Kyoto Protocol in December 2007 and has made a commitment to reduce its greenhouse gas emissions to 60% of 2000 levels by 2050. The Australian Government is implementing a strategy for tackling climate change through the Carbon Pollution Reduction Scheme. The government has indicated that agriculture will be included in the scheme; this sector contributes 16% of the country’s greenhouse emissions, mainly methane from enteric fermentation in ruminants. However, the form of this participation will not be determined until 2013 and discussions are continuing.

**Positive externalities**

As noted, the sugar industry is the cornerstone of many towns and communities on the northeast coast of Australia. It is estimated that it employs directly around 5250 people on farm, 3120 in the harvesting sector and 7359 in mills. Logistics, marketing, research, representation and refining contribute another 753 people, giving a total of around 16 482 direct employees. The workforce is skilled and adaptable. Indirectly, around 30 000 persons rely on the industry for their livelihood. The centre of mass that the industry provides keeps rural communities alive and means that services such as education, health and finance are maintained.

**The industry’s ability to match sustainability criteria**

Political positioning, encroachment from urban development, increased environmental scrutiny, competition for land use from other crops and forestry and the diversity of the sugar producing regions are all factors that will affect the industry’s ability to match sustainability criteria.

The diversity of climate, geographic location, cane variety, water availability and soil conditions all dictate farm practice. For instance, in the Burdekin dry tropics, cane fires are commonplace as heavy crops and furrow irrigation make trash blanketing difficult. In most other regions, cane fires were replaced with green cane harvesting and green trash blanketing years ago. Maintaining the ability to burn cane when necessary requires an understanding of farming systems that the public and media may not be inclined to develop, leading to simplistic proposals for quick solutions.

Urban development on productive cane land and land-use change to trees or other crops create tension, particularly around production tonnages that are necessary for mill viability. Taxation incentives are available for forestry developments that are not applied to cane growing. Urban expansion into cane areas brings increased public scrutiny of farm practices such as application of fertiliser and chemicals.

We consider that the industry’s biggest challenge in terms of legislative outcomes is the rise of the urban green vote and the willingness of politicians to chase this bloc with simplistic solutions. At the same time, regional electorates are seen as unlikely to change hands with the consequence that their concerns can be largely dismissed.

This was clearly evident in an announcement during a recent Queensland State election campaign of measures to reduce pollution on the Great Barrier Reef by 50% in five years by targeting only the sugar and grazing industries.

By contrast to the legislative approach, the industry, in partnership with the Commonwealth government, other peak industry bodies and regional natural resource management groups, has committed to a program of cooperative improvements in farm practices.

The five-year Reef Rescue program will focus on new technology to assist growers make best use of their inputs of fertiliser, chemicals and irrigation water to deliver a more profitable business with greatly reduced environmental footprint. It will be responsible for the delivery of incentives for accelerated uptake of better management practices in the reef catchments.
The representative organisation, CANEGROWERS Australia, produces a Public Environment Report on a regular basis (Wrigley et al., 2008 is the latest). This is designed to provide a comprehensive reference for those interested in the growing sector’s environmental progress.

It details the risk management and continual improvement of new farm practices being undertaken by growers for economic, social and environmental sustainability. The reports measure progress and highlight growers’ willingness to continually strive to do more, provided that it is practical, is supported by science and delivers a benefit.

The organisation has also been proactive in developing booklets, DVDs and a range of communication tools to assist farmers to adopt improved management practices.

**Research**

It is fair to say that most research in the Australian sugar industry has a sustainability focus. Work on reducing fertiliser requirements, improving the targeting and effectiveness of pesticide use, drought tolerance of new varieties, and farming systems with lower inputs and lower losses are all examples of research dedicated to improving sustainability.

An examination of the research programs of BSES Limited and the Sugar Research and Development Corporation will demonstrate an almost-universal emphasis on the triple bottom line in research outcomes.

**Conclusion**

The Australian industry probably operates under more environmental scrutiny and control than most, has less government protection than most and consequently suffers less interference in its commercial arrangements than most.

It dedicates considerable resources to improving its sustainability and will continue to improve. However, it will also be likely to find its operations curtailed through political interference based on simplistic, populist environmental concerns.

**REFERENCE**

## Appendix 1

### Laws, legislation and regulation relevant to agricultural farm practices in Australia

<table>
<thead>
<tr>
<th>Legislation</th>
<th>Description</th>
</tr>
</thead>
</table>
| **Water Act 2000** | - Water Licences  
- Water Allocations  
- Land and Water Management Plans  
- Regulates clearing of vegetation in and around water ways |
| **Great Barrier Reef Protection Amendment Act 2009 (Qld)** | - Legislation and regulations to improve water quality entering the Great Barrier Reef that is directed at sugarcane farmers and graziers in the Wet Tropics, Burdekin Dry Tropics and Mackay Whitsundays.  
- Regulates certain works that take or interfere with water from watercourses, lakes, springs, aquifers or overland flow  
- Development Permit required for physical construction of works to take or interfere with water in a watercourse  
- Development Permit required for bores |
| **Integrated Planning Act** | - Care and protection of native plants, animals and habitat in Queensland  
- Protects areas of environmental significance |
| **Nature Conservation Act 1992 (Qld)** | - For plants and animals declared as pests  
- Places obligations on landholders in relation to the control, sale, keeping and transport of declared pests in Queensland |
| **Land Act 1994 (Qld)** | - Places obligations on leaseholders when it comes to noxious plants eg may require the lessee to destroy plants |
| **Local Government Act 1993 (Qld)** | - Local Government Minister has power to declare any bird, animal, insect, fungus, matter or thing to be a pest within the meaning of that Act |
| **Vegetation Management Act** | - Clearing of vegetation in and around water ways  
- Clearing of vegetation on both freehold and leasehold land  
- Property Map of Assessable Vegetation |
| **Vegetation Management and Other Legislation Amendment Bill 2009** | - Management and clearing of regrowth vegetation and regrowth watercourses  
- Wet Tropics, Burdekin Dry Tropics and Mackay Whitsundays |
| **Soil Conservation Act 1986** | - Designed to conserve and prevent soil erosion |
| **Wild Rivers Act 2005 (Qld)** | - Aims to preserve river systems the State Government identifies as having all, or almost all, of their natural values intact |
| **Wild River Code** | - Sets out requirements that must be met by proposed development |
| **River Improvement Trust Act 1940** | - Designed to improve the flow of water courses |
| **Environmental Protection Act 1994** | - Protect the environment in Queensland  
- Wide range of mechanisms  
- Eg aerial spray drift |
| **Environmental Protection and Biodiversity Conservation Act 1999 (Cth)** | - Provides protection to nationally significant aspects of the environment  
- Farmers may require approvals if new activities significantly impact on matters of environmental significance  
- World Heritage Properties  
- National Heritage places  
- Wetlands  
- Threatened animal and plant species and ecological communities  
- Migratory species  
- Commonwealth marine areas |
<p>| <strong>Local laws</strong> | - By local governments |
| <strong>Fire and Rescue Service Act 1990</strong> | - Permits for burning in certain situations |
| <strong>Agricultural Standards Act 1994 (Qld)</strong> | - Imposes quality and control stands on ‘agricultural requirements’ (seed, fertiliser, lime or stock food) |</p>
<table>
<thead>
<tr>
<th>Act/Code</th>
<th>Description</th>
</tr>
</thead>
</table>
| Agricultural and Veterinary Chemicals Act 1994 (Commonwealth) | Regulate agricultural and veterinary chemicals  
APVMA (Australian Pesticides and Veterinary Medicines Authority)  
Registration of agricultural and veterinary chemicals ensures that users have access to approved products that are correctly packaged and labelled with all necessary limitations, precautions and directions for use  
Sub-section 10(c) of the Agricultural and Veterinary Chemicals Code provides that a person may apply to the NRA (National Registration Authority) for approval of a label for containers for a chemical product. |
| Agricultural and Veterinary Chemicals Act 1994 (Qld) | Responsible for regulation, registration and control of agricultural and veterinary chemicals  
Chemicals must be registered under the ‘AgvetCode’  
Usage of agricultural chemicals |
| Chemical Usage (Agricultural and Veterinary) Control Act 1988 (Qld) | Use of chemicals according to approved processes eg labels |
| Chemical Usage (Agricultural and Veterinary) Control Amendment Regulation 2009 (Qld) | Use of chemicals according to approved processes to support the Great Barrier Reef Protection Amendment Act 2009 |
| Chemical Usage (Agricultural and Veterinary) Control Regulation 1999 | Use of chemical products under previously approved labels and permits  
Restrictions for Endosulfan eg must have Chemcert, FarmCare or similar |
| Agricultural and Veterinary Chemicals Code Act 1994 (Commonwealth) | An Act to make provision for the evaluation, registration and control of agricultural and veterinary chemical products, and for related matters, for the purposes of the Agricultural and Veterinary Chemicals Act 1994 |
| Agricultural Chemicals Distribution Control Act 1966 (Qld) | DPIF  
Controls the aerial distribution of chemicals and the ground distribution of herbicides  
Contract distribution and application of chemicals |
| Health Act 1937 (Qld) | Prohibits any person under 17 years of age to take part in the distribution, mixing and loading of chemicals |
| Stock Act 1915 (Qld) | Control the introduction of stock into Queensland and movement of stock in Queensland |
| Plant Protection Act 1989 (Qld) | Controls the introduction and movement within Queensland of plants, soil and other things  
Puts in place quarantine restrictions eg Plant Quarantine Areas for sugarcane |
| Plant Breeders Rights Act 1994 (Commonwealth) | For new plant varieties |
| Fisheries Act 1994 | Protection of fish habitat areas.  
Section 123 makes it an offence to unlawfully destroy marine plants, i.e without a permit  
Maintenance of drains on-farms involving marine plants  
Code for self-assessable development |
Provides for the establishment, control, care and development of the Great Barrier Reef Marine Park  
Establishes the Great Barrier Reef Marine Park Authority  
Provides for zoning plans and plans of management |
| Great Barrier Reef Marine Park (Environmental Management Charge–General) Act 1993 (Commonwealth) | An Act to impose a charge on the grant or transfer of certain permissions under the Great Barrier Reef Marine Park Regulations, so far as that charge is neither a duty of customs nor a duty of excise |
### Voluntary activities relevant to agricultural good farm practices

<table>
<thead>
<tr>
<th>Category</th>
<th>Activities</th>
</tr>
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</table>
| Chemcert                                | • Participation in workshops  
                                | • Payment of relevant certification fees                                    |
| Land and Water Management Plans         | • Participation in workshops  
                                | • Sometimes prior to water trading  
                                | • Sometimes on a voluntary basis                                            |
| Nutrient Management                     | • ‘6 Easy Steps’ Workshops  
                                | • Recommended fertiliser application rates by industry  
                                | • Development of nutrient management plans  
                                | • Soil testing  
                                | • Water quality testing  
                                | • Shed meetings, farm walks, bus tours etc                                    |
| Farm Plans                              | • Farm Productivity Assessment Workshops  
                                | • Compass workshops, Compass workbook                                        |
| Controlled traffic farming with GPS     | • Benefits nutrient, sediment reduction and water efficiency                 |
| guidance                                | • Benefits nutrient, chemicals, sediment reduction and water efficiency     |
| Green cane harvesting and trash         | • Benefits nutrient, sediment reduction and water efficiency                 |
| blanketing                              | • Benefits water efficiency and sediment reduction                          |
| Water efficient irrigation eg low        | • Benefits nutrient, sediment reduction and water efficiency                 |
| pressure overhead irrigation            | • Benefits water efficiency and sediment reduction                          |
| Environment Audits                      | • By CANEGROWERS  
                                | • 1996  
                                | • 2004                                                                 |
| Public Environment Reports              | • By CANEGROWERS  
                                | • 2004  
                                | • 2006  
                                | • 2008                                                                 |
| Best Management Practice Booklets       | • By CANEGROWERS and BSES  
                                | • Series of six initially                                                    |
LA DURABILITE ET L’INDUSTRIE SUCRIERE AUSTRALIENNE

Por

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MOTS-CLES: Australie, Durabilité, Législation.

Résumé
CET ARTICLE passe en revue les obligations législatives, environnementales et sociales dont a fait face l’industrie sucrière australienne. Il conclut que l’industrie australienne fonctionne dans un contexte environnemental et de contrôle plus contraint que la plupart des autres industries, qu’elle a moins de protection gouvernementale que la plupart mais qu’elle souffre de moins d’interférence dans ses négociations et aménagements commerciaux que la plupart des autres industries.

LA SOSTENIBILIDAD Y LA INDUSTRIA AZUCARERA AUSTRALIANA

Por

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PALABRAS CLAVE: Australia, Sostenibilidad, Legislación.

Resumen
ESTE ARTÍCULO examina los requisitos legislativos, ambientales y sociales que enfrenta la industria azucarera de Australia. El informe concluye que la industria Australiana probablemente opera bajo mayor escrutinio y control ambiental que la mayoría, tiene menos menos protección del Gobierno que la mayoría, pero sufre menos interferencias en sus arreglos comerciales que la mayoría.
REPORT ON PROFIT, PEOPLE AND PLANET. HOW DOES THE SOUTH AFRICAN SUGAR INDUSTRY REACT?

By

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KEYWORDS: Sustainability, Protection, Environment, Social, Research.

Abstract

THE ISSCT Executive Committee has initiated a study to assist affiliates to deal with the increasing calls for sustainable production systems. Sustainability refers to the triple bottom line or the people, planet and profit philosophy. Most of the ISSCT’s endeavours of recent history have been directed at improving the profit component of that philosophy in both field and factory. The people and planet have not enjoyed as much attention. The Executive Committee decided to appoint a Task Force to report on sustainability and this report provides the results of the study in the South African Sugar Industry. Field and factory activities, which identified the Industry’s actions in respect of the stewardship of both people and the planet, were established after dialog with both the miller and grower fraternities in South Africa. Views on the successes and shortcomings are highlighted and research needs identified. In the context of the profit component, a report on the macro economics of issues such as total production, total revenue earned, grower’s total income and total numbers of employees is given.

Introduction

The South African sugar industry is diverse, combining the agricultural activities of sugarcane cultivation with the manufacture of raw and refined sugar, syrups, specialised sugars and a range of by-products.

The cane growing sector comprises approximately 42 300 registered growers farming predominantly in Kwa Zulu-Natal, with a substantial investment in Mpumalanga and some farming operations in the Eastern Cape. Sugar is manufactured by five milling companies with 14 sugar mills operating in these cane growing regions.

The industry produces an estimated average of 2.3 Mt of sugar per season. About 60% of this sugar is marketed in the Southern African Customs Union (SACU), member states being Botswana, Namibia, South Africa, Lesotho and Swaziland. The remainder is exported to markets including those in Africa, Asia and the Middle East (South African Sugar Association, 2008).

Profit component in the triple bottom line

The South African sugar industry makes an important contribution to the national economy, given its agricultural and industrial investments, foreign exchange earnings, its high employment and its linkages with major suppliers, support industries and customers.

Revenue

Based on revenue generated through sugar sales in the SACU region as well as world market exports, the South African sugar industry is responsible for generating an annual estimated average direct income of R7 billion. This constitutes R4.5 billion in value of sugarcane production.

Market competitiveness

Governments strategic support for the South African sugar industry recognises the distorted nature of the world market for sugar and the severe impact of producer support measures on price
determination on the global market. Based on these considerations government support includes intervention in the following three areas: Tariff protection against disruptively low world sugar prices; provision for the establishment of equitable export obligations for millers and growers; and the Sugar Co-operation Agreement between the members of the Southern African Development Community (SADC). Member states of SADC being Democratic Republic of Congo, Tanzania, Angola, Zambia, Malawi, Mozambique, Zimbabwe, Botswana, Namibia, South Africa, Lesotho, Swaziland, Mauritius, Seychelles and Madagascar.

**Tariff protection**

The industry is protected through a dollar-based reference price tariff system that is based on the long-term average world price for sugar, adjusted for distortions, which only delivers protection when the world price drops below this level.

**Equitable export obligations**

The South African sugar industry exports approximately 40% of its production to the world market at prices substantially below the domestic sugar price. In order to distribute exposure to the world market equitably among growers and millers, a redistribution of proceeds is effected via the South African Sugar Association. The Sugar Act and the Sugar Industry Agreement provide regulatory support for the redistribution of proceeds.

**The Southern African Development Community Sugar Co-operation Agreement**

The main objectives of the SADC Sugar Co-operation Agreement are:

- To promote, within the region, production and consumption of sugar and sugar-containing products according to fair trading conditions and an orderly regional market in sugar for the survival of the sugar industries in all sugar producing member states, in anticipation of freer global trade;
- To create a stable climate for investment, leading to growth and development of sugar industries in the member states;
- To improve the competitiveness of the sugar producing member states in the world market;
- To facilitate the sharing of information, research and training with a view to improve the efficiency of growers, millers and refiners of sugar in 7 member states;
- To facilitate the development of small and medium sugar enterprises; and
- To create stable market conditions in the member states so as to encourage the rehabilitation and development of all sugar industries with a view to facilitate direct foreign investment and the creation of employment opportunities.

**People component in the triple bottom line**

**Employment**

The South African sugar industry falls under the Sugar Industry bargaining council and all wages and salaries are negotiated accordingly for the entire industry. Direct employment within the sugar industry is approximately 77,000 jobs, which represent a significant percentage of the total agricultural workforce in South Africa.

Indirect employment in sectors such as fertiliser, fuel, chemical, transport, food and services is estimated at 350,000. Approximately one million people depend on the sugar industry for a living. Sugar mills typically employ in the region of 450 people per mill. Growers typically allocate 1 labourer per 1000 tons cane.

The sugar mills provide a diverse and intensive technical employment field and career opportunities. The skills base includes engineers and artisans, accountants, cane supply staff, human resource support, training and development staff. Involvement with local schools offering career guidance and work shadow opportunities for learners.
Social obligations

The industry’s initiatives in the areas of economic transformation could best be summarised under its commitment to Broad-based Black Economic Empowerment (BBBEE), with focus on land reform, farmer support services, employment equity and enterprise ownership.

Agricultural land made available to black growers

The industry has set a target of 30% black ownership of freehold sugarcane land by 2014. In order to achieve this, an independent land reform entity called INKEZO Land Company has been formed to help streamline the process.

Agricultural support services

The industry has a long history of promoting and supporting small-scale farmers on tribal land. Building on the extensive infrastructure and network of the growers and millers, the industry has been able to engage effectively in ongoing delivery related projects. The South African Cane Growers Association provides technical skills training for new and emerging cane growers via the Agiseta scheme, mentorship programs, accounts and financial management workshops, regional economic advisors, a grower support service officer and assistance with special VAT and diesel dispensation for small-scale growers. The milling companies provide extensive support services in support of the cane growing operations of small-scale, medium-scale and large-scale black growers. The South African Sugar Association trains emerging medium-scale growers, offers certificate courses to users in sugarcane agriculture, technology transfer and extension initiatives and various community outreach programs.

Employment equity

All participants in the industry promote compliance with the Employment Equity Act and have integrated Employment Equity and Skills Development Plans in place that are monitored and updated annually. These have targets for recruiting, developing and promoting people from designated groups.

Ownership profile

Substantial progress has been made towards improving the ownership profile of the industry. Initiatives embarked upon by major South African milling companies have resulted in black ownership of manufacturing activities being 12% and of refining activities being 7%.

Social investment

The incidence of HIV and AIDS impacts directly upon the industry and its workforce. Meeting the challenge of this disease is a priority. Activities include school education awareness programs and funding home-based care initiatives for individuals and households infected and affected by HIV and AIDS. Individual grower groups and millers have and are funding clinics and orphanages in the rural areas.

In 1965 the industry launched the Sugar Industry Trust Fund for Education (SITFE). SITFE has provided bursaries to more than 9000 students, financed school building projects, given assistance to tertiary institutions and worked closely with community based educational authorities.

Relevant social legislation

Compensation for Occupational Injuries and Diseases Act, 130 of 1993.
Competition Act, 89 of 1998.
KwaZulu Natal Heritage Act 10 of 1997
Land Reform (Labour Tenants) Act, 3 of 1996
Medical Schemes Act, 131 of 1998.
National Heritage Resources Act, 25 of 1999
Pension Funds Act, 24 of 1956.

Planet component of the triple bottom line

The South African Sugar Association (SASA) actively promotes sound and sustainable environmental practices within the industry in line with national legislation and international requirements. This is achieved through its support for Local Environmental Committees (LEC) located in the sugar producing areas and also through active involvement in promoting sustainable resource management through a Memorandum of Understanding with WWF South Africa.

The industry is involved in a Southern African Development Community wide initiative aimed at establishing a guide on environmental best management practices for the regional sugar industries.

Individual grower groups have adopted the Sustainable Sugarcane Farm Management System (SuSFarMS), an environmentally friendly farming system developed by growers in conjunction with WWF South Africa. The system is currently being rolled out to other grower groups in the industry and has been endorsed by SASA.

The various milling companies have adopted environmental management systems such as the ISO 14001 and similar local derivatives.

The industry demonstrates a very high level of environmental awareness and practices (McCarthy, 2008) and has:

- Cut back on planting in estuaries and delicate ecosystems and is now often actively leading local conservation and awareness organisations;
- Cut back on burning of cane at harvest especially where it impacts negatively on adjacent land use and has reintroduced green cane harvesting in several areas;
- Reduced the use of more harmful chemicals in weed control;
- Reduced the emissions from milling factories to the atmosphere and impacts on run-off and stream quality.

Relevant environmental legislation

Conservation of Agricultural Resources Act, 43 of 1983.
Fertilisers, Farm Feeds and Agricultural and Stock Remedies Act, 36 of 1947.
National Environmental Management Amendment Act, 8 of 2004.
Natal Nature Conservation Ordinance 15 of 1975
National Road Traffic Act, 93 of 1996.
National Roads Amendment Act, 24 of 1996.
Sugar Act, 9 of 1978.

**Short comings**
The current short comings of the South African sugar industry in relation to its ability to conform to present day sustainability are:

- Input costs are high resulting in lower profits.
- The industry is heavily reliant on natural weather conditions; global warming could have a negative effect.
- Land claims and the loss of sugarcane supply to the mills.
- Loss of sugarcane land to township development schemes.
- Loss of labour due to HIV and AIDS.
- Lack of adoption of international energy norms within the sugar mills in order to improve factory operating efficiencies and reduce fuel bills.
- Disagreement between millers and growers.

**Research requirements**
The industry will require the following research to ensure it will have the tools to be fully sustainable:

- Transport methods and supply chain efficiency.
- Need to bring national government on board to implement a suitable long term sustainable electricity tariff that facilitates and promotes the sugar industry to produce and export electricity into the national grid.
- Alternative uses of sugarcane.
- Ethanol production.
- Reducing input costs.
- Improved crop nutrition and water use efficiency.
- Land usage planning.
- Integrated pest management and bio-security.
- Farming systems in relation to environmental management.

**REFERENCES**


RAPPORT SUR LE PROFIT, LES POPULATIONS ET LA PLANETE. 
COMMENT REAGIT L'INDUSTRIE SUCRIERE SUD AFRICAINE?

Par

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MOTS-CLES: Durabilité, Protection, Environnement, Social, Recherche.

Resumé
Le comité exécutif de l’ISSCT a initié une étude afin d’aider ses membres à faire face à l’augmentation de demandes concernant les systèmes de production durable. La durabilité se réfère aux trois principes philosophiques de base, les populations, la planète et le profit. La plupart des efforts de l’ISSCT dans son histoire récente a été orienté sur l’amélioration de la composante « profit » de cette philosophie tant au niveau du champ que de l’usine. Les populations et la planète n’ont pas jouis de la même attention. Le comité exécutif a décidé de former une équipe renforcée pour réaliser un rapport sur la durabilité et ce rapport donne des résultats sur l’étude de l’industrie sucrière Sud-Africaine. Les activités au champ et à l’usine qui ont guidés les actions de l’industrie dans le respect des intérêts des gens et de la planète, ont été établies après un dialogue avec les associations fraternelles d’usiniers et planteurs en Afrique du Sud. Les points de vue sur les succès et les défauts ont été soulignés les besoins en recherche identifiés. Dans le contexte de la composante « profit », un rapport sur les aspects macroéconomiques des questions majeures telles que la production totale, les gains économiques totaux, le revenu total du planteur et le nombre total d’employés est donné.

REPORTE SOBRE GANANCIAS, GENTE, Y EL PLANETA. CÓMO REACCIONA 
LA INDUSTRIA DEL AZÚCAR SUDAFCRANO?

Por

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PALABRAS CLAVE: Sostenibilidad, Protección, Investigación Social, Medio Ambiente.

Resumen
El comité ejecutivo de ISSCT ha iniciado un estudio para ayudar a los afiliados para que puedan responder a las exigencias cada vez mayores de sistemas de producción sostenible. Sostenibilidad se refiere a la triple cuenta de resultados o la filosofía de gente, planeta y ganancias. La mayoría de los esfuerzos recientes de la ISSCT han sido dirigidos a mejorar el componente de ganancias de esa filosofía tanto en campo y como en fábrica. Los componentes de gente y el planeta no han disfrutado de tanta atención. El Comité Ejecutivo decidió nombrar a un grupo de trabajo para informar sobre la sostenibilidad, y este informe proporciona los resultados del estudio en la industria azucarera de Sudáfrica. Las actividades de campo y de fábrica, las cuales identificaron las acciones de la industria con respecto a la administración de la gente y el planeta, fueron establecidas después de diálogos con las organizaciones de ingenios y cultivadores en Sudáfrica. Se resaltan puntos de vista sobre los logros y deficiencias, y se identifican necesidades de investigación. En el contexto del componente ganancias, se da un informe macro económico en cuestiones tales como la producción total, total de los ingresos ganados, los ingresos totales del productor y número total de empleados.
SUSTAINABILITY IN SUGARCANE PROCESSING IN BRAZIL

By

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KEYWORDS: Sustainability, Biofuels, Bioplastics, Residues, Productivity.

Abstract

SUSTAINABILITY involves the three ‘Ps’: People, Planet and Profit. Brazilian sugarcane is a sustainable industry that has made significant gains in its sustainability over the last 30 years. A typical mill today can process twice as much sugarcane with the same equipment and with approximately the same energy, maintenance, labour, water, etc., so that twice as much product can be produced. All residues are recycled back to sugarcane fields. The use of energy and chemicals in processing are also considerably reduced. The use of sugarcane bagasse, other carbohydrates from sugarcane, production of bioplastics and second and third generation biofuels represent new avenues for increased sustainability. The entire Brazilian sugarcane production chain has to be very well prepared for a more intense scrutiny of sustainability.

Introduction

Sustainability is a complex concept involving the so called three ‘Ps’: People, Planet and Profit.

The production and processing of sugarcane in Brazil is definitely a sustainable industry and is a very important activity in that country.

It occupies less than 10% of the commercial agricultural area or less than 2% of the total arable land, but the sector generates 1.5% of the Brazilian GNP (same order of magnitude as Uruguay).

The sector is responsible for around 1 200 000 jobs, and employees are paid better than in other Brazilian agribusiness, and have superior labour rights.

The investment needed to generate these jobs is much less than in other sectors of the Brazilian economy.

In the automotive sector, about US$80 000 is needed per job while, in sugarcane processing, only about US$12 000 is required.

Considering all jobs in the production of ethanol and cars, ethanol-driven cars generate 20 times more Brazilian jobs than the gasoline ones.

In terms of impacts on the environment, it is acknowledged that any economic activity has an impact, but the sugarcane agribusiness consistently demonstrates that its production and processing are feasible in the long term.

This is the case in São Paulo state, where 70% of the sugarcane is produced and where the environment protection agencies are more active and the legislation more comprehensive.

In São Paulo, there are many sugarcane mills that have been in operation for more than 50 years and their productivity is still increasing.

Life style indices of the population in the sugarcane cities are improving and are better than in other cities.

Sugarcane processing in Brazil can be summarised in the flowsheet presented in Figure 1.
Sustainability

The sustainability aspects that can be emphasised in the processing are:

- Productivity,
  - Producing more with the same equipment;
- Efficiency,
  - Producing more with the same raw material,
  - Reducing losses and emissions – pollution;
- Energy,
  - Producing more with the same energy;
- Water,
  - Producing more with the same water;
- Chemicals,
  - Producing more with the same chemicals,
  - Less contamination – pollution.

Due to the Oil Crisis in 1973 and a severe debt and currency crisis, Brazil established the National Alcohol Program in 1975, called the Proalcool. This program, the most important renewable energy program in the world for replacement of fossil fuels with biofuels, created a
steady demand and established the logistics needed for its use. Government support and private investment and then competitive production led to the gains in sustainability in the sugarcane sector.

In terms of investment and production costs, losses and possible development of bottlenecks, the most important part of sugarcane processing is the sugar extraction mill (or diffuser) and the distillery. Gains in productivity in sugar extraction (the most expensive and energy intensive part of processing) are shown in Figures 2, 3, 4 and 5.

![Evolution of Milling Capacity](image)

Fig. 2—Evolution of milling capacity.

Figure 2 shows that a typical mill today can process twice as much sugarcane with the same equipment and with approximately the same energy, maintenance, labour, water, etc., so that twice as much product can be produced.

At the same time as the productivity doubled, the efficiency (the amount of sugar in the juice compared with the sugar in the raw material) also increased (Figure 3).

![Evolution of Milling Efficiency](image)

Fig. 3—Evolution of milling efficiency.
The efficiency gains are driven mainly by the need to produce more with the same raw material (sugarcane) that is the main cost driver.

In Figure 4, it can be seen that the productivity in ethanol plants (measured here by the fermentation time) also almost doubled. Simultaneously, the efficiency also increased significantly (Figure 5).
The water used (from a water body) dropped considerably from 5.6 m³/tonne of cane in 1990 to around 1.8 m³/tonne of cane, through reduction and reuse (closed circuits). Water returns are now treated, with more than 98% reduction in organic matter.

All residues, including solids such as filter cake, from the juice clarification, and vinasse, from the bottom of the distillation column, are 100% recycled back to sugarcane fields, with better performance than the corresponding chemical fertilisers.

The use of energy and chemicals in processing are also considerably reduced due to the synergistic behaviour of the distillery adjacent to the sugar factory.

All streams containing sugars, even low quality, may be sent to the distillery as well as the richer molasses or even syrups, because there are no losses when this sugar is converted into other valuable products such as ethanol.

Attending to two different markets (sugar and fuel—ethanol) makes the production more flexible, robust and less dependent on subsidies. The industry is also less prone to big losses due to excessive volatility in the prices of commodities.

The use of energy is another important aspect of the processing. Because sugarcane bagasse can be used to fuel all energy needs, the amount of renewable energy in the final product (ethanol biofuel) is about nine times greater than the energy used from fossil fuels.

This is much better than when sugar beet, wheat or corn is used at the same production level.

Today the use of sugarcane bagasse represents around 16% of the total primary energy used in Brazil. There is a surplus of energy in the best processing units and electricity (and excess bagasse) is being sold in some cases, representing around 10% of the total sales of these more modern mills.

Although most energy is generated from hydroelectricity in Brazil, the surplus energy generated from sugarcane makes it possible to save water during the drier periods of the year, when sugarcane is harvested and processed.

There is considerable potential to increase electricity exports, which will add to the sustainability of the Brazilian economy.

This is because co-generation investments are much cheaper, and the electricity will be added to the grid much faster than with any other generation option.

Finally, the carbohydrates from sugarcane, as well as the ‘excess’ energy, can be used for establishing so called biorefineries, replacing practically all imported products from petroleum, such as plastics.

This will add significantly to sustainability on a global scale. Even fertilisers can be produced from sugarcane residues through gasification and other processes, as well as other biofuels such as biogas, biogasoline and biodiesel.

Production of bioplastics from plants in factories annexed to a sugarcane processing plant is the most likely to succeed. This represents a very interesting method of CO₂ (carbon) ‘sequestration’ and storage.

The so-called second and third generation biofuels, based on the use of cellulosic residues and CO₂ as a raw material, respectively, are also very likely to be competitive with the sugar-based biofuels and products, in the short or mid-term.

This will add efficiency to the entire production. For this to happen, however, considerable international research efforts are needed.

More R&D in the broad area of sustainability is an urgent need for the short term, and forums such as ISSCT can facilitate decisions on what to prioritise.

The entire sugarcane production chain has to be very well prepared for a more intense scrutiny of sustainability, particularly as biofuels become rational alternatives to fossil fuels.
DURABILITE DANS LE TRAITEMENT A L’USINE DES CANNES A SUCRE AU BRESIL

Par

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MOTS-CLÉS: Durabilité, Biocarburant, Bioplastiques, Résidus, Productivité.

Résumé
LA DURABILITÉ implique les trois P: Population, Planète et Profit. La canne à sucre brésilienne est une industrie durable qui a progressé significativement dans ce domaine de la durabilité depuis les 30 dernières années. Aujourd’hui une usine typique peut traiter deux fois plus de cannes avec le même équipement et avec approximativement la même énergie, maintenance, main-d’œuvre et quantité d’eau, ce qui génère aussi deux fois plus de produits. Tous les résidus sont recyclés et utilisés dans les champs de cannes. L’utilisation d’énergie et de substances chimiques dans le traitement à l’usine sont aussi considérablement réduits. L’utilisation de la bagasse et d’autres matières carbonées issues de la canne à sucre ainsi que la production de bioplastiques et les biocarburants de seconde et troisième génération représentent de nouvelles voies pour accroître la durabilité des opérations. Toute la chaîne de production brésilienne doit être très bien préparée pour une exigence accrue en matière de durabilité.

SOSTENIBILIDAD EN EL PROCESAMIENTO DE CAÑA DE AZÚCAR EN BRASIL

Por

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PALABRAS CLAVE: Sostenibilidad, Biocombustibles, Bioplásticos, Residuos, Productividad

Resumen
LA SOSTENIBILIDAD involucra Gente, Planeta y Rentabilidad. La industria azucarera brasileña es sostenible y ha obtenido ganancias significativas en su sostenibilidad durante los últimos 30 años. Hoy en día un ingenio azucarero puede moler el doble de la caña de azúcar de lo que hacía antes, con el mismo equipo y usando aproximadamente la misma cantidad de energía, mantenimiento, mano de obra, agua, etc., por lo que se puede obtener el doble de producto. Todos los residuos son reciclados y vuelven a los campos de caña. El uso de energía y de productos químicos en el proceso también se ha reducido considerablemente. El uso del bagazo, de otros carbohidratos de la caña, producción de bioplasticos y los biocombustibles de segunda y tercera generación, representan las nuevas líneas para el incremento de la sostenibilidad. La cadena completa de producción de azúcar del Brasil tiene que estar preparada para un escrutinio más intenso en cuanto a la sostenibilidad.
MONITORING THE HARVESTING OF SUGARCANE AND
GENERATION OF YIELD MAPS IN REAL TIME

By

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KEYWORDS: Sugarcane, Precision Agriculture, Yield Mapping,
Wholestalk Weigh System, Harvest Monitoring.

Abstract
In a given area or plantation it is common to determine the variability in production
that exists between harvested sugarcane fields or lots. The agroindustrial sugar sector in
the Cauca River Valley of Colombia has appropriate mechanisms for determining and
managing the variability of production among the cane lots, but it has not had sufficient
alternatives for determining the variability within them. At present, the preharvest task
of cutting the cane is done manually in most of the area, while the subsequent lifting of
the stalks is done with self-driven equipment. CENICAN has developed a system that
can be installed on the cane lifters, which records the weight of each bundle and its
distribution position. The data are stored and transmitted by cell phone to a computer
where they can be visualised for carrying out a precise monitoring of the harvest and
generating yield maps. This work describes the structure of the system developed, the
methodology for obtaining and transmitting the data, and how to interpret and analyse
the yield maps. An analysis of a field harvest, for which it is known where there was
fertilisation and where not, shows the value of each weight recorded. In this case, the
best estimate of the production in the field is obtained by averaging the data from six
consecutive bundles. Both the system for obtaining the data and the methodology for
their analyses and the generation of yield maps can be implemented in other agricultural
sectors.

Introduction
Numerous studies have developed systems for monitoring and recording the yield and
generation of production maps in manual and mechanically harvested sugarcane crops. Different
tools have been developed for obtaining yield maps. Pierossi and Hassauani (1997) installed four
compression load cells on an infield (haulout) wagon in a chopper harvesting system; other studies
for producing production maps in different crops are reported by Cox et al. (1997).

Pagnano and Magahlaes (2001) used production maps to determine variability in sugarcane.
Molin et al. (2003) generated production maps of manually harvested burned cane by relating the
weight of a bundle from a mechanical loader to a georeferenced distance.

The weight of each grab was determined from the total weight of the load gathered in the
wagon and the number of grabs.

The majority of the area planted by the agro-industrial sugar sector in the Cauca River
Valley of Colombia is harvested manually, and the cane is piled in the field (windrow) to be picked
up by self-propelled loaders and deposited in wagons that are taken to the factory by tractor or
truck.

The Colombian Sugarcane Research Center (CENICAN) has been developing different
systems for the georeferenced weighing of sugarcane. In 2006 the Agronomy Program began the
instrumentation of a commercial-scale self-dumping wagon with load cells on its four sides,
together with a data storage system for weighing the Center’s experiments at the different sugar mills. In this way they could obtain the weights of each plot with its treatments, whether by manual or mechanical harvesting. Later a system for georeferencing (GPS) was installed in the system in order to generate yield maps.

In 2007, the Geomatics Area at CENICAÑA began developing a geo-referenced weighing system that also made it possible to transmit the data and generate intrafield yield maps in real time, using the instrumentation of the cane lifter. This system was designed for use in the manual harvesting of sugarcane. It is important to quantify the within-field production in different zones. This is to allow management of the crop variability and to make more efficient use of resources when taking investment decisions with respect to a production area. The GIS and geostatistics are used to quantify the differences in production within the lots and then generate isoproduction curves; while spatial analysis is used to carry out studies of economic efficiency and evaluate the differences in intralot productivity.

Materials and methods

Weighing system

A compression load cell (5000-kg capacity) was mounted in a mechanical system with four disks (Figure 1), which allowed pressure to be exerted on the cell every time that cane is picked up with the loader. The load cell then generates an electrical analog signal (millivolts), which is recorded by the weight indicator (Prometalic Scales, model PRO-1500), which stabilises the signal and sends the weight data via a serial port to a datalogger. For the georeferencing and sending the information, equipment was used that integrates a GPS and a wireless modem (Enfora Spider, model MT-G 2208). For the synchronisation, storage and transmission of the information, a datalogger (Campbell Scientific, model CR1000) was used with a dedicated a program written in CR Basic language.

![Load Cell](image)

Calibration

After mounting the load cell on the disks, a preliminary calibration of the weighing equipment was done, setting weights with predetermined values; and the corresponding voltage was
induced in the load cell. The PRO-1500 indicator was used in this process in order to establish the zero value of the weighing system.

**Data recording**

The datalogger has four serial ports, of which two are used for connecting the GPS and the load cell. The weight indicator records the signal of the load cell, displays it visually and sends it to the serial port of the datalogger. The datalogger synchronizes the recorded weight with the data on the position given by the GPS. Then the data are stored in the datalogger and sent by the modem through the GPRS (General Packet Radio Service) network to a Web server, where they are kept in a database.

The process of recording the data is controlled by the loader operator who presses a recording button that communicates with the datalogger. The end user accesses the information using a Web explorer with SVG (Scalable Vector Graphic) support. The communication between the server and the user is done via a Hypertext Pre-processor (PHP, a Personal Home Page tool).

**Sending the data**

The cellular modem uses the GPRS commercial network for sending the information that is extracted from the serial port of the datalogger, making use of AT commands for obtaining the data from the GPS, which includes the UTM (Universal Transverse Mercator) hour, geographic position and the quality of these data (Figure 2).

**Productivity maps**

The yield map is generated with the information on the weight and its geographic coordinates. This map depends on two variables:

- The number of furrows per windrow of cane (5 or 6 cut furrows piled in a single row) and;
- The distance between the furrows.

The loader obtains the data from a nominated area every time that a certain distance is run, piling the cane to be lifted later; it is necessary to obtain the starting and the end points of each run of the lifter and the respective weighing in order to determine the production area. Each production area is connected to the previous one, which means that every time that the lifting process is begun,
the operator has to mark the starting point of the windrow to establish the first production zone. Figure 3 shows the diagram for producing the yield maps in real time in each windrow.

All data are stored in a PostgreSQL-PostGIS database; and by means of a geospatial operation, the information is obtained on the plantation/lot in which the cane is being picked up.

The PHP language was used to create an application that takes into account the position, weight, the azimuth between points, and the distance parameters between furrows and number of furrows per windrow to generate the production areas.

The output format of the graphic that the PHP generates is SVG, which is an XML (Extensible Markup Language) format that can be seen on the Web explorer. The application calculates the yield for each production area in TCH (tonnes of cane per ha), classifying each area in a range of yield.

![Figure 3—Diagram for generating the yield map on-line in each windrow.](image)

**In-field evaluation**

The system was evaluated in a manually harvested field at Cenicaña (3° 21’ latitude North, 76° 18’ longitude West) in November 2008. The lot had an area of 8748 m², and was planted with variety CC 85–92, at a distance of 1.5 m between furrows.

There were two fertilisation treatments: one with fertigation (windrow 3, 6 and 8) and the other with conventional fertilisation, applied mechanically (windrow 2, 4 and 9). There was one check without fertilisation (windrow 1, 5 and 7).

Each treatment had three replications formed by six furrows along field 8. An 80-hp lifter (Metalagro, model AC-80) was used, on which the previously described equipment was installed. In total, there were nine windrows, each one formed by six furrows corresponding to each treatment and replication.

The furrows were oriented in an east-west direction, and each treatment was placed along the furrow (108 m long). In total, the equipment recorded 318 weights with their corresponding coordinates. The windrow weights were analysed, yield determined and the results graphed.

The data were analysed using descriptive statistics and Kolmogorov-Smirnov’s and Shapiro-Wilks’ normality tests. An analysis of variance was applied for the treatments, using Tukey’s test, with a 95% level of confidence.

**Results and discussion**

The descriptive statistics for each windrow are given in Table 1. Windrow 1 and 7 had values very close to the mean, the median and the mode and a coefficient of asymmetry less than 1, indicating a symmetric distribution of frequencies; thus they are near a normal distribution.

Similar results were obtained when the Shapiro-Wilks test was applied to all the windrows. All the windrows, except for 1, 7 and 9, had data discrepancies (very high), which should be revised
carefully, as well as the very low weight values in windrow 3 and 6. The null hypothesis for this test was that the weights of each windrow were characterised by a normal distribution (P-value > 0.05).

**Table 1**—Descriptive statistics for the weight (kg) of the nine windrows.

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Windrow 1</th>
<th>Windrow 2</th>
<th>Windrow 3</th>
<th>Windrow 4</th>
<th>Windrow 5</th>
<th>Windrow 6</th>
<th>Windrow 7</th>
<th>Windrow 8</th>
<th>Windrow 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>318</td>
<td>337</td>
<td>347</td>
<td>377</td>
<td>366</td>
<td>338</td>
<td>325</td>
<td>343</td>
<td>365</td>
</tr>
<tr>
<td>Median</td>
<td>310</td>
<td>330</td>
<td>338</td>
<td>365</td>
<td>350</td>
<td>338</td>
<td>333</td>
<td>330</td>
<td>360</td>
</tr>
<tr>
<td>Mode</td>
<td>310</td>
<td>330</td>
<td>320</td>
<td>325</td>
<td>380</td>
<td>370</td>
<td>315</td>
<td>345</td>
<td>310</td>
</tr>
<tr>
<td>SD</td>
<td>40.91</td>
<td>69.71</td>
<td>78.52</td>
<td>89.51</td>
<td>85.55</td>
<td>49.00</td>
<td>30.51</td>
<td>81.25</td>
<td>53.67</td>
</tr>
<tr>
<td>Sample variance</td>
<td>1674.03</td>
<td>4860.03</td>
<td>6164.98</td>
<td>8011.70</td>
<td>7318.47</td>
<td>2401.21</td>
<td>930.96</td>
<td>6602.32</td>
<td>2880.86</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>-0.54</td>
<td>4.05</td>
<td>8.58</td>
<td>4.60</td>
<td>5.31</td>
<td>1.81</td>
<td>0.38</td>
<td>14.46</td>
<td>-0.02</td>
</tr>
<tr>
<td>Coefficient of asymmetry</td>
<td>0.03</td>
<td>1.19</td>
<td>2.22</td>
<td>1.69</td>
<td>2.11</td>
<td>-0.83</td>
<td>-0.39</td>
<td>3.28</td>
<td>0.80</td>
</tr>
<tr>
<td>Range</td>
<td>170</td>
<td>385</td>
<td>455</td>
<td>470</td>
<td>395</td>
<td>230</td>
<td>135</td>
<td>470</td>
<td>205</td>
</tr>
<tr>
<td>Minimum</td>
<td>230</td>
<td>210</td>
<td>225</td>
<td>235</td>
<td>245</td>
<td>245</td>
<td>185</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Maximum</td>
<td>400</td>
<td>595</td>
<td>680</td>
<td>705</td>
<td>640</td>
<td>415</td>
<td>385</td>
<td>720</td>
<td>500</td>
</tr>
<tr>
<td>Sum total</td>
<td>11,120</td>
<td>12,800</td>
<td>12,505</td>
<td>12,425</td>
<td>10,600</td>
<td>10,820</td>
<td>8445</td>
<td>11,335</td>
<td>12,425</td>
</tr>
<tr>
<td>No. of data</td>
<td>35</td>
<td>38</td>
<td>36</td>
<td>33</td>
<td>32</td>
<td>26</td>
<td>33</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>Level of confidence (95.0%)</td>
<td>14.05</td>
<td>22.91</td>
<td>26.57</td>
<td>31.74</td>
<td>32.54</td>
<td>17.67</td>
<td>12.32</td>
<td>28.81</td>
<td>18.73</td>
</tr>
</tbody>
</table>

The ANOVA revealed that windrow 1, 5, 6 and 7 were similar among themselves, but different from windrow 2, 3, 4, 8 and 9.

Similar tests were done with the TCH data in accordance with data for just one weighing (one bundle), two consecutive weighings (two bundles) and so on, successively, until reaching yield values for 8 bundles together.

Table 2 shows the P-values for the Shapiro-Wilks and Kolmogorov-Smirnov tests, the average and standard deviation. The TCH values that met with a normal distribution were those for 6 and 8 bundles. Figure 4 shows the different statistical treatments carried out with the data.

**Table 2**—Tests for determining normality of the data in accordance with the number of bundles.

<table>
<thead>
<tr>
<th>Quantities of bundle</th>
<th>Indicator (1)</th>
<th>Indicator (2)</th>
<th>Average (TCH)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>133.8</td>
<td>53.79</td>
</tr>
<tr>
<td>2</td>
<td>&lt;0.01</td>
<td>&gt;0.15</td>
<td>125.4</td>
<td>30.75</td>
</tr>
<tr>
<td>4</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>123.5</td>
<td>23.57</td>
</tr>
<tr>
<td>6</td>
<td>&gt;0.1</td>
<td>&gt;0.15</td>
<td>121.8</td>
<td>18.78</td>
</tr>
<tr>
<td>8</td>
<td>&gt;0.1</td>
<td>&gt;0.05</td>
<td>122.2</td>
<td>18.15</td>
</tr>
</tbody>
</table>

(1) Shapiro-Wilks, (2) Kolmogorov-Smirnov.
If the P-value is >0.05, there is not sufficient evidence for suggesting that the data do not follow a normal distribution.
For carrying out the geostatistical analyses, work was done using the TCH data, grouping the different quantities of bundles and using the one that described a normal performance in order to guarantee greater precision in the analyses (Rey and Ovalles, 2001).

The geostatistical analysis concluded that when using six bundles, a theoretical exponential model and an anisotropic at 303°, which corresponds to the direction of the bundles in the field, the best spatial dependence was found, using the ratio $C/(C_0+C) = 100\%$; a $C_0$ of 0.00 nugget effect (sampling error); a spatial relation (sill) of 407.56; a range of 52.16 and a mean square error for the cross-validation of 0.94.

It was also found that, by increasing the number of grabs in the cluster, the proportion that measures spatial dependence $C/(C_0+C)$ increased 14% with 2 bundles to 78% with 4 bundles, and 100% with 6 and 8 bundles. Although the spatial dependence was high with 4 bundles, there are doubts as to the normality of the data; thus it was not selected.

Figure 5 is the result of the data analyses and shows the yield maps (TCH) based on the ranges of production quartiles that correspond to the yield map as is presented in real time and the result of using the method of interpolation found (exponential).

Both maps show the particular condition of the field having an unfertilised area, where the production was different but where there were spatial variations along each windrow.
Conclusions

Currently, the system is used to weigh all experimental plots in Cenicaña.

Some sugar mills are beginning to incorporate the system in their harvesting process (cane loaders and computers).

The system can be used when the harvesting is done with self-dumping equipment unlike other systems.

With the system developed, yield maps can be generated in real time based on weight values and their coordinates.

By means of a computer connected to the Internet, those who are interested in monitoring the harvesting can learn about its progress and the within-lot variability of yield in any place.

It’s necessary to analyse all dates of each lot or field because continuous data do not necessarily mean that they comply with the criterion of normality. In the analysis of the case in this document, which grouped 2, 6 and 8 bundles, there was sufficient evidence to suggest that the data followed a normal distribution.

The system can be employed for analysing production in other agricultural systems such as fruits, oil palm, rice, potatoes or similar crops.

The system is being patented initially in Colombia.

REFERENCES


SUIVI DE LA RECOLTE DE CANNE A SUCRE ET GENERATION DE CARTES DE RENDEMENT EN TEMPS REEL

Par

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MOTS CLÉS: Canne à Sucre, Agriculture de Précision, Cartographie de Rendement, Système de Pesage de Cannes, Entières pour Suivi de Récolte.

Résumé

Dans une région donnée ou une plantation, il est courant de déterminer la variabilité de production entre les différents champs ou parcelles récoltés. Le secteur agro-industriel de la vallée de la rivière Cauca de Colombie a des moyens appropriés pour mesurer et gérer la variabilité de production entre les parcelles de canne, mais n’a pas de méthode alternative pour mesurer leur variabilité intrinsèque. Actuellement, la récolte de la canne est manuelle dans la presque totalité de la zone, alors que le chargement est effectué avec des chargeuses automotrices. CENICAÑA a développé un système installé sur les chargeurs qui permet d’enregistrer le poids de canne dans chaque grappin ainsi que sa position géographique. Les données sont stockées et transmises par téléphone portable vers un ordinateur qui permet de les visualiser pour un suivi précis de la récolte et pour générer des cartes de rendement. Ce papier décrit la structure du système développé, la méthodologie pour l’obtention et la transmission des données, ainsi que la façon d’analyser et d’interpréter les cartes de rendement. L’analyse de la récolte d’un champ où les zones fertilisées ou non sont connues montre la valeur de chaque poids enregistré. Dans ce cas, la meilleure estimation de la production du champ est obtenue en moyennant les données de six grappins successifs. Le système pour obtenir les données, la méthodologie pour leur analyse et la génération des cartes de rendement peuvent tous être implémentés dans d’autres secteurs agricoles.
MONITOREO DE LA COSECHA DE CAÑA DE AZUCAR Y GENERACION DE MAPAS DE RENDIMIENTO EN TIEMPO REAL

Por

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PALABRAS CLAVE: Caña de Azúcar, Agricultura de Precision,

Resumen
EN UNA zona determinada o de plantación es común determinar la variabilidad de la producción que existe entre los campos de caña de azúcar cosechada o lotes. El sector azucarero agroindustrial en el valle del río Cauca, Colombia cuenta con los mecanismos adecuados para determinar y manejar la variabilidad de la producción entre lotes de caña, pero no ha tenido suficientes alternativas para determinar la variabilidad dentro de ellos. En la actualidad, la labor de corte antes de la cosecha de la caña se realiza manualmente en la mayoría de la zona, mientras que el alce de los tallos cortados se hace con equipos autopropulsados. CENICAÑA ha desarrollado un sistema que puede ser instalado en las alzadoras de caña, este registra el peso de cada uñada y su posición geográfica. Los datos son almacenados y transmitidos por teléfono celular a una computadora donde se puede visualizar para llevar un monitoreo preciso de la cosecha y adicionalmente generar mapas de rendimiento. Este trabajo describe la estructura del sistema desarrollado, la metodología para la obtención y transmisión de los datos, y cómo interpretar y analizar los mapas de rendimiento. Un análisis de la cosecha de un campo, del cual se sabe donde hubo fertilización y donde no, muestra el valor de cada peso registrado. En este caso, la mejor estimación de la producción en el campo se obtuvo promediando los datos de seis uñadas consecutivas. Tanto el sistema de obtención de los datos y la metodología para análisis y generación de mapas de rendimiento pueden ser aplicadas en otros sectores agrícolas.
MONITOREO DE LA COSECHA DE CAÑA DE AZUCAR Y GENERACION DE MAPAS DE RENDIMIENTO EN TIEMPO REAL

Por

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PALABRAS CLAVE: Caña de azúcar, Agricultura de Precision, Yield Mapping, Wholestalk Weigh System, Harvest Monitoring.

Resumen

En una zona determinada o de plantación es común determinar la variabilidad de la producción que existe entre los campos de caña de azúcar cosechada o lotes. El sector azucarero agroindustrial en el valle del río Cauca, Colombia cuenta con los mecanismos adecuados para determinar y manejar la variabilidad de la producción entre lotes de caña, pero no ha tenido suficientes alternativas para determinar la variabilidad dentro de ellos. En la actualidad, la labor de corte antes de la cosecha de la caña se realiza manualmente en la mayoría de la zona, mientras que el alce de los tallos cortados se hace con equipos autopropulsados. CENICAÑA ha desarrollado un sistema que puede ser instalado en las alzadoras de caña, este registra el peso de cada uña y su posición geográfica. Los datos son almacenados y transmitidos por teléfono celular y transmitidos a una computadora donde se puede visualizar para llevar un monitoreo preciso de la cosecha y adicionalmente generar mapas de rendimiento. Este trabajo describe la estructura del sistema desarrollado, la metodología para la obtención y transmisión de los datos, y cómo interpretar y analizar los mapas de rendimiento. Un análisis de la cosecha de un campo, del cual se sabe donde hubo fertilización y donde no, muestra el valor de cada peso registrado. En este caso, la mejor estimación de la producción en el campo se obtuvo promediando los datos de seis uñadas consecutivas. Tanto el sistema de obtención de los datos y la metodología para análisis y generación de mapas de rendimiento pueden ser aplicadas en otros sectores agrícolas.
EFFICIENCY OF MECHANICAL CANE LOADING IN EGYPT

By

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KEYWORDS: Wholestalk Cane Loading, Cane Loader Efficiency, Sugarcane Transport Systems, Harvest Scheduling.

Abstract

THE CANE growing area along the Nile valley in Upper Egypt has expanded. Most of farmer holdings are small, typically ranging from 0.5 to 1 hectare. Cane delivery schedules and consequently harvesting dates mainly depend on the delivery allocation and the date of harvest last season. The mill administration assigns a transport vehicle (main vehicle) for each farmer according to the schedule. Farmer/s harvest and transport cane from inside field/s (using a tractor-pulled-trailers) to temporary storage sites at which the main vehicle/s are loaded. Loader efficiency can be low due to time losses associated with travel from one storage site to another. To achieve reasonable efficiency of the loader, storage sites may be amalgamated allowing greater utilisation of loaders. This procedure may increase the infield transport distance which may reduce the rate of cane supply from fields, thus contributing to increased cane delivery delay. Farmers may have to transport a part of the main vehicle load to the storage site the previous day to secure continuous operation of the loader. In this study, loader efficiency, loading rate, the percentage of main vehicle/s load/s delayed more then 24 h and cane collection efficiency were studied. In most cases, one main vehicle is assigned to each farmer, where a trailer pulled by tractor is used to transfer cane from inside the field to the storage area. Results show that total efficiency of the loader was 75% in case of loading lorries in a large storage area and 81% in case of railway wagons loaded at a station. Average total efficiency of the loader was 61% when loading decauvelle wagons distributed in several storage areas within the same production region. Efficiency of loading tractor trailers in the field was 54%. Maximum efficiency was observed to be achieved if the loader works for the full operational day in one storage area. Cane collection efficiency was variable for the variable operating conditions. The percent of cane delayed more than 24 h was also estimated. Large temporary storage areas at which lorries are loaded with cane, and cane loading stations for railway wagons may represent more optimal conditions for loader operation. The paper discusses the efficiency of loader operation under a range of variable conditions, and related cane delivery delay. The results highlight the role of loader operation efficiency as a factor determining the adoption of mechanical loading of sugarcane. Recommendations for proper operation of cane loader are suggested.

Introduction

Due to soil and water limitations, the sugarcane growing area in Upper Egypt is limited to about 350,000 feddan (150,000 hectares). Average production has been maintained at over 120 t/ha for several years and may be classified as one of the highest cane yielding areas in the world. Cane-to-mill delivery activities are performed according to schedules (prepared by the mill administration) which determine the date of harvesting and the main transport vehicle. According to
the schedule, the common procedure is to each day assign a main vehicle to each farmer, thus allowing for low productivity of the harvesting and transport activities. Farmers harvest and transport cane to temporary storage areas at the trans-loading sites for the main vehicles. Cane has to be loaded again to the main vehicles. These temporary storage areas are the main area where mechanical loading of cane is undertaken, to load cane on the main transport vehicles to the mill.

Efforts to mechanise cane loading started more than 20 years ago when the Ministry of Agriculture initiated three mechanisation companies for sugarcane. The largest of these companies (Aswan Mechanisation Company) invested large amounts of its capital to purchase and rent cane loaders (especially Bell loaders). Despite the unlimited chances for operating these loaders, the company lost a large part of their investment and could not afford to replace the loaders at the end of their useful life. Therefore mechanical loading activities reduced from about 8% to less than 2%. Operating loaders at lower efficiency may have been one of the most important factors contributing to the loss of such investments and subsequent decline in the percent of mechanical loading. The number of workers ready to load has been declining because most of them prefer to find other easier jobs. Therefore the cost of cane loading has been constantly increasing.

Uichanco (1976) and Edilbert and Uichanco (1977) stated that cane loading is an arduous task which limits the productivity of manual cane cutters. In the Philippines, cane cutters can cut and load only one tonne a day. The wider use of mechanical loaders in the sugar industry can be an intermediate step in improving harvesting efficiency. Cochran and Whitney (1976) reported that Louisiana conditions require that sugarcane be burned and cut ½ to 1 day ahead of the loader and then transported to the mill. Libunao (1978) reported that, in the Philippines, sugarcane is loaded manually in trucks or carts for in-field transport. Cane loaders carry on their shoulders about ten to twenty cane stalks, from the ground to the trucks, through a ladder or ramp placed on any side of the truck. Manual loading complements sugarcane cleaning in the field which is also done manually.

Blackburn (1984) described the Bell self-loading trailer drawn by a wheeled tractor, designed and developed in South Africa. Cane is cut manually and formed into heaps or bundles. When loading takes place, the trailer is manoeuvred into position and its skids are dropped. A wire or chain attached to the winch is then passed around the bundle and draws it up the ramp into the trailer. Bell self-loading trailers are also used, with local modifications, in Trinidad and have been used since 1968 in the Philippines. Yang and Wang (1993) evaluated the performance of mechanical loading of sugarcane and compared it with the traditional manual loading on flat and sloping lands under two different yielding conditions. The manual loading efficiency was 0.54 t/ man/h in comparison with 23.9 t/h for mechanical loading. Saif El-Yazal and Abdel-Mawla (1994) compared mechanical and traditional loading and transporting of sugarcane. The performance of the two mechanical systems was tested. The first was a 5 tonne capacity self-loading trailer equipped with a loading boom and the second was the grab loader. The self-loading trailer transported 6.4 t/h. The locally made trailer transported 5.3 t/h from a field 0.5 km from the store location, when loaded by the grab type loader.

Hansen et al. (1998) and Eggleston et al. (2001) conducted intensive studies on the problems of deterioration due to cane delay. The authors highlighted the problems caused by deterioration with different processing stages and recommended that the transport process be accelerated to reduce delivery delay. Abdel-Mawla (2000) studied mechanical loading of sugarcane and stated that efficient management of cane area and delivery system may facilitate increasing mechanical loading productivity and control cane delivery delay. Legal and Requis (2002) reported that the South African sugar industry relies on a large number of small-scale growers for a significant part of its production. In that respect, the management of the cane harvest and supply to the mill represents the key-issue regarding both the reduction of burn to crush delays, the regularity of deliveries and the reduction of production costs.
Abdel-Mawla and El-Lithy (2006) developed an expert system approach for selecting a cane transport system. They specified the possibility of mechanical loading as one of the most important qualifiers that attract farmers for selecting the cane delivery system. Meyer (2007) stated that, in South Africa, only about 2% of the annual crop is currently harvested mechanically. It is estimated that 40% of the whole stalk sugarcane is either loaded manually onto transport vehicles or stacked in 3–5 tonne bundles to be transported by a self-loading tractor trailer/trailer combination. The remaining tonnage is mechanically loaded by grab and push-pile loaders onto a wide range of vehicles which transport the cane either directly from the fields, or indirectly from trans-loading zones to the mill.

The cane delivery process includes two transport links. In the first link the farmers use camels, carts or tractor-trailers to transport cane from inside fields to temporary stores (trans-loading sites). In the second link (according to the mill delivery schedule) a main transport vehicle is assigned to each farmer. The main vehicles may be a decauvelle-wagon or a railway-wagon if available in the region otherwise a wheel vehicle is used. In case of mechanical loading, farmers use tractor-trailers for infield transport to supply cane to the main vehicles waiting in the trans-loading site.

To maintain continuous operation of the loader, variable regulations have been arranged depending on the type of vehicles and other conditions. The study aimed to evaluate the efficiency of mechanical loading at the conditions under which the loader is operated.

**Materials and methods**

The area of cane planted for each mill is organised into regions. Each region is divided into plots bounded by irrigation channels, drainage channels, and rod system expanded in the agricultural area. Cane fields planted in the same plot may be owned by several farmers (prevailing holding sizes ranged from 0.5 to 1 hectare) and may not be of the same ratoon. Cane delivery schedules and consequently harvesting dates mainly depend on the ratoon and date of last season harvesting. Therefore, fields of the same region assigned for cane harvesting at certain dates may not be neighbours and main vehicles may be loaded at different trans-loading sites. Because cane is harvested manually and infield transport may depend on carts and such slow means, the mill administration assigns one main vehicle (daily) for each farmer. The main vehicle may be a decauvelle or a railway wagon depending on the availability; otherwise, a wheeled vehicle may be used. In case of mechanical loading, the farmers use a trailer pulled by a medium size tractor for infield transport.

A large temporary store (trans-loading site) is that in which the loader can work for a full operational day. Such sites may exist in one of the following conditions: 1) At large fields of the sugar company, governmental farms or large farmer holdings where lorries are shipped with cane. This may represent a small part of the total production area of sugarcane. 2) At the main railway line of Upper Egypt where trans-loading sites are established for transporting the cane crop of farms on both sides of the railway line. The railway wagons transport less than 3% of the total cane production.

Field measurements were undertaken at several locations in Upper Egypt. A Bell mechanical loader was used in the study. The mechanical efficiency of the Bell loader was assessed in the three most likely operational scenarios. These included:

1. Loading vehicles in one site:
   Lorries loaded in one trans-loading site.
   Railway wagons loaded simultaneously in a railway trans-loading site.

2. Loading vehicles in several sites:
   Decauvelle wagons or trucks waiting single or combined in 2, 3, 4 or 5 vehicles in the same trans-loading site.
3. Infield mechanical loading.
In the three scenarios, no time losses due to maintenance or repair were recorded. Hence, these losses are not considered in determining loader efficiency.

**Loader efficiency**

The loader efficiency was determined by multiplying the efficiency of loading an individual vehicle by the efficiency of continuous loading.

Total efficiency of loader $L_E$ may be computed as the following:

$$L_E = L_{E1} \times L_{E2}$$

where:

- **Efficiency of loading individual vehicle ($E_1$)**
  Only time lost while loading a vehicle was considered.

- **Efficiency of continuous operation ($E_2$)**
  Only time lost for the loader to shift from one vehicle to another was considered.

**Loading rate**

The loading rate for the full operational day of the loader was computed using the following equation.

$$L_R = \frac{\text{Sum vehicle loads (tonnes)}}{\text{Operation hours / day}}$$

where:

- $L_R$ = Loader rate (t/h).

**Load delays**

According to the schedule of the mill, decauvelle wagons are distributed to the locations of temporary stores before sunrise and pulled back to the mill (loaded with cane) that afternoon.

The time available for infield transport may expand till the wagon is completely loaded, and this depends on the rank of the vehicle/store considered for mechanical loading.

Where there is simultaneous loading of railway wagons, loading duration (time available for infield transport) of each vehicle may expand to be equal to the full operational day.

The time available for infield transport for a vehicle waiting for the loader, may be determined as follow:

$$T_{FT} = \frac{V_{2L} \times V_{2N} \times S_{rank}}{L_R}$$

where:

- $T_{FT}$ = Time available for infield transport, h.
- $V_{2L}$ = Average load of the main vehicle, tones.
- $V_{2N}$ = Number of main vehicles in a store.
- $S_{rank}$ = Rank of the site considered for mechanical loading.

In case of mechanical loading, the loader operator informs each farmer with the rank of loading his vehicle two days early.

The farmer may estimate the quantity of infield cane transported from the early morning till the loader starts to load his wagon and transport the rest of the vehicle load from the field to the store at the previous day.

The percent of a vehicle load to be transported from the previous day (delayed more than 24 h) to secure continuous operation of the loader may be computed as follow:
QD % = The percent of the main vehicle load delayed more than 24h,

\[ Q_D \% = 100 \left( 1 - \frac{V_{1R} \times T_{FT}}{V_{2L}} \right) \left( \frac{V_{1N}}{V_{2N}} \right) \]

\( V_{1R} \) = The rate of infield transport by a tractor-trailer, t/h.

\( V_{1N} \) = Number of infield transport vehicle/s that supply cane to main vehicle/s. The ratio of \( (V_{IN} / V_{2N}) \) in common conditions equal to the unity.

The same form may be used to estimate the quantities of infield transported while loading railway wagons simultaneously. In this case, loading duration (time available for infield transport, \( T_{FT} \)) for each wagon may be equal to the operational hours of the day.

**Cane collection efficiency**

Cane collection efficiency is a measure of cane losses due to mechanical loading. The loader performs loading cycles as fast as possible to maximise the loader rate and income. Cane stalks may be scattered from the loader grab and the loader may pass over while working. Even though a worker may be assigned to collect scattered cane, some cane may be lost or damaged. Loader collection efficiency was determined as follows:

**Results and discussion**

**Mechanical loading in large stores**

Where lorries are loaded in a large trans-loading site, the loader loads each lorry individually. Before the loader starts loading a vehicle, the full cane load should be ready in the site. Mechanical loading accelerates the transport cycle and may facilitate repeated trips of a lorry from the trans-loading site to the mill. During mechanical loading, the lorry driver adjusts the lorry to the most suitable position for the loader to manoeuvre while loading to minimise the loading cycle time and maximise loader rate. Loading lorries individually in a large site was accomplished at a maximum mechanical loading rate of 23.1 t/h. Total efficiency computed for a full operational day while loading lorries in a large site was not less than 75%.

In the case of the railway wagons, large trans-loading stations are established with a sufficient number of wagons for a full day of operation of the loader (8 h/day or more). In most cases each wagon is assigned for a farmer. The wagons may be detached and separated little distance apart to allow more room for each farmer to unload his cane opposite to the wagon. The loader operator loads several wagons simultaneously while farmers continue to transport cane from fields. To maintain continuous operation of the loader, each farmer determines the quantity of cane that could be transported within loading duration and transports the rest of the load the previous day. Loading duration for each wagon is considered equal to the loader operational hours of the full working day. A maximum operational efficiency of 81% was achieved for loading railway wagons due to the maximum use of time because of simultaneous loading. Average loading rate was 21.9 t/h.

**Mechanical loading in several stores**

If the cane is transported from inside the field to load single vehicles waiting at the road, then the loader operator has to move along the road to load vehicles one by one. Decauville wagons are distributed on the rail slide opposite to the fields before sunrise and pulled back to the mill (loaded) afternoon. The wagons considered for mechanical loading during the operational day ranked and the full load of each wagon should be ready on time. Vehicles may be combined to more than one vehicle in the same site to save the loader time losses due to travel among small sites. When decauville wagons are combined in a store, the loader operator may load all vehicles in the same site simultaneously. Similarly, trucks may be waiting on the road opposite to fields. They may also be single or combined according to the possibility of having more than one vehicle together.
Lorries are loaded individually because they perform repeated transport trips during the operational day.

The larger the number of vehicles combined in the same store, the longer the average field to store distance and the lower the infield transport rate as shown in Figure 1.

Therefore, farmers within a certain area who wish to use mechanical loading may plan to establish a common trans-loading site. It has been observed that under such conditions the maximum number of vehicles that could be combined in a common store was five while combining three vehicles may be more practical. Loader efficiency improves from 60% to 74% when loading several vehicles in one store as indicated in Figure 2.
The loader operator prepares a schedule for the loader work along the operational day that ranks sites in which vehicles are waiting for mechanical loading. The farmer determines the quantity of cane to be transported in the same day of loading and transport the rest of the vehicles load from the previous day. Therefore a percent of the vehicle load may be delayed more than 24 h as shown in Figure 3.

![Figure 3—Percent of vehicle loads delayed more than 24 h to maintain continuous loader operation.](image)

**Mechanical loading inside fields**

Several attempts to operate loaders for loading decauville wagons on a portable slide line have been tried in the experimental farm of the sugar company. Other trials to load tractor-trailers inside the field were also evaluated. The results show that mechanical loading of cane inside the field is completed at low rate and poor efficiency. This is due to the loader having to move around the stationary vehicle to collect cane piles and travel back to discharge the grab load inside the vehicle. The poor performance of the loader is mainly because of moving across furrows and irrigation channels. The irregular form and size of cane piles due to manual harvesting contributed the poor performance of mechanical loading inside the field. In these conditions, the loader rate was limited to 13 t/h. Efficiency of mechanically loading a stationary vehicle inside the field was up to 54%.

**Comparison loader efficiency**

Loader rate, loader efficiency and cane collection efficiency are the main criteria to compare the performance of the loader in certain conditions.

Figure 4 shows the loader rate in the four scenarios under which the loader was assessed. Loading lorries resulted in the maximum rate of 23.1 t/h due to the manoeuvres made by the lorry driver to facilitate accomplishing the loading cycle in shorter time. Simultaneous loading of railway wagons resulted in a loading rate of about 22 t/h due to the continuous loader operation. The rate of
loading an individual decauvelle wagon was much higher than the continuous rate computed for the operational day. The loader loses a lot of time, change arrangement, location and people that largely reduced loading rate to be 17.1 t/h.

The loading rate for decauvelle wagons on portable slide or tractor-trailers in the field was as low as 13 t/h.

Figure 4—Comparison loader rate.

Figure 5 shows loader efficiency for the four scenarios under which the loader was assessed. The large store is a yard at which the farmers bring their cane to be loaded on the main transport vehicle.

When the loader has finished loading a lorry, the loaded vehicle needs to turn around and leave.

Shifting from one lorry to another represents an inefficiency in the process. Efficiency of loading lorries in a large store was found to be about 75%.

Loading railway wagons simultaneously may represent the most suitable conditions for maximising loader efficiency.

The trial included 12 railway wagons in one station. Each farmer is assigned a wagon and he piles his cane in a windrow opposite to his wagon. Twelve tractor trailers each belong to a farmer supply cane from fields.

The loaders start loading a wagon and, when the cane for a wagon is loaded, the operator shifts to another wagon. Efficiency of loading railway wagons was as high as 81%.

Due to the time taken in travelling from one store to another, the loader efficiency of loading vehicles in several stores was limited to about 61%.

Due to difficult field conditions, the loader efficiency of infield loading was the lowest of all operations (54%).
Figure 6 shows cane collection efficiency in the four scenarios. The efficiency determined represents the cane damaged with the loader wheel in the store yard or that lost in the field. Cane losses recorded were 0.8%, 0.7%, 0.6% and 1.1% for loading lorries, railway wagons, decauvelle and infield loading respectively. Corresponding collection efficiencies were 99.2%, 99.3%, 99.4% and 98.9%. It seems that the rough surface of the field contributed more scattered cane and less collection by the labour.
Conclusion

Mechanical loading of sugarcane in the Nile Valley in Upper Egypt is required to substitute for the decreasing availability of labourers for manual loading. Farmers have been striving to increase the number of loaders available. Practical procedures can be developed which facilitate the operation of cane loaders at increased efficiency and productivity. Operational strategies which facilitate profitable operation of cane loaders will lead to a significant increase in the proportion of the crop which is mechanically loaded. The following items may represent some of the possible procedures to secure applicable efficiency of loader operation:

1. Loaders should be operated in conditions that facilitate reasonable efficiency, such as:
   a) At railway cane trans-loading sites. Operating loaders in such sites should attract more farmers to request cane transportation by railway. Consequently, more wagons would be loaded at each trans-loading site, increasing loader operation hours per day. Efficiency would be improved and cane delivery delay reduced.
   b) At large trans-loading sites (cane loading stations) such as at government farms, sugar company farms and private large farms.
   c) At farms belonging to strong cooperatives that may force their members to act as one large farm to facilitate mechanisation of such operations.

2. Efforts should be exerted to gradually adjust scheduled date of harvesting as well as the determined harvest allocation for each cane plot area. In this case, each cane growing plot will represent a large farm where a large temporary trans-loading site could be established with no reduction of infield transport rate. Early success of such a strategy is expected, since farmers have been striving for mechanical loading. Management of cooperatives and mill administration can also use their influence to convince farmers to change and optimise allocation of harvesting units to fields and harvesting dates.

3. Gradual adjustments to a common date of harvesting for neighbouring fields could be applied through the cane delivery schedules prepared annually by the mill administration.

4. Avoiding operating a loader for loading single vehicles, or at small trans-loading sites which are distributed far from each other.

5. Avoid infield mechanical loading unless the irrigation system has been developed to reduce intensive furrows, channels and transverse ridges. A system of harvesting that results in uniform windrowing or piling of cane after harvesting may help to improving infield loader efficiency.

REFERENCES


L’EFFICIENCE DU CHARGEMENT MECANIQUE
DE LA CANNE EN EGYPTE

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LA ZONE de culture de la canne le long de la vallée du Nil dans la Haute Egypte s’est étendue. Les parcelles des agriculteurs sont restreintes, typiquement dans une gamme de 0.5 à 1 hectare. Le planning de livraison de la canne et donc la date de récolte pour chaque champ dépend principalement du quota de livraison et de la date de la récolte précédente. La direction de l’usine attribue une unité de transport (cellule motrice principale) à chaque agriculteur en se basant sur le planning. Les agriculteurs récoltent et transportent la canne de l’intérieur des champs (avec une remorque attelée à un tracteur) vers des zones de transfert où les cellules motrices principales sont chargées. L’efficience du chargement peut être faible suite au temps perdu pendant le transport entre zones de transfert. Afin d’obtenir une efficience raisonnable du chargeur, les zones de transfert peuvent être fusionnées permettant ainsi une meilleure utilisation des chargeurs. Cette procédure peut augmenter la distance de transport à l’intérieur des champs, ce qui pourrait réduire la fréquence de livraison, contribuant ainsi à des délais de livraison accrus. Les agriculteurs pourraient avoir à transporter le jour précédent, une partie du chargement de la cellule motrice principale vers la zone de transfert afin d’assurer l’opération continue du chargeur. Dans cette étude, l’efficience du chargeur, la fréquence de chargement, le pourcentage des voyages des cellules motrices principales retardés plus de 24 heures ainsi que l’efficience du ramassage de canne ont été déterminés. Dans la plupart des cas, une cellule motrice principale est attribuée à chaque agriculteur et une remorque attelée à un tracteur est utilisée pour transférer la canne de l’intérieur du champ vers la zone de transfert. Les résultats montrent que l’efficience totale du chargeur était de 75% pour le chargement de camions dans une grande zone de transfert et de 81% dans le cas de wagons de chemin de fer chargés à une station. L’efficience moyenne totale du chargeur était de 61% pour le chargement de wagons ‘decauvelle’ distribués dans plusieurs zones de transfert dans la même région de production. L’efficience du chargement au champ des remorques attelées au tracteur était de 54%. Une efficience maximale était obtenue si le chargeur travaille toute la journée dans une seule zone de transfert. L’efficience du ramassage de la canne était variable pour les différentes conditions d’opération. Le pourcentage de canne retardé plus de 24 h fut aussi estimé. De grandes zones de transfert où les camions sont chargés de canne et des stations de chargement pour les wagons de chemin de fer pourraient offrir des conditions plus optimales pour l’opération du chargeur. Ce papier discute de l’efficience de l’opération du chargeur sous une gamme de conditions variables et le retard à la livraison qui en découle. Les résultats soulignent le rôle de l’efficience de l’opération du chargeur comme facteur déterminant l’adoption du chargement mécanique de la canne à sucre. Des recommandations pour une opération adéquate du chargeur de canne sont suggérées.
EFICIENCIA DEL CARGUE MECÁNICO DE CAÑA EN EGIPTO

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PALABRAS CLAVE: Cargue de Caña Entera, Eficiencia del Cargador de Caña, Sistemas de Transporte De Caña de Azúcar, Programación de La Cosecha.

Resumen
El área de cultivo de caña a lo largo del valle del Nilo en el Alto Egipto se ha ampliado. El área de las unidades de producción es pequeña, normalmente entre 0.5 a 1 hectárea. Los plazos de entrega de caña y, en consecuencia las fechas de recolección para cada campo dependen principalmente de la asignación de entrega y la fecha de cosecha de la temporada pasada. La administración del ingenio asigna un vehículo de transporte (vehículo principal) para cada agricultor en función de la programación. El agricultor/es cosechan y transportan la caña desde los campos interno/s (usando remolques tirados por tractor) a los sitios de almacenamiento temporal en los que el vehículo principal/es es cargado. La eficiencia del cargue puede ser baja debido a pérdidas de tiempo asociadas con los viajes de un sitio de almacenamiento a otro. Para alcanzar una eficiencia razonable del cargador, los sitios de almacenamiento deberían estar centralizados de manera que permitan una mayor utilización de los cargadores. Este procedimiento puede aumentar la distancia de transporte interno, lo que puede reducir la tasa de abastecimiento de caña desde los campos, lo que a su vez contribuiría a incrementos en la demora en la entrega de caña. Para garantizar la operación continua del cargador, los agricultores pueden tener que transportar una parte de la carga del vehículo principal al sitio de almacenamiento desde el día anterior para garantizar la operación continua del cargador. En este estudio la eficiencia del cargador, la tasa de carga, el porcentaje de vehículo/s principales o carga/s retrasados más de 24 horas y la eficiencia de recolección de caña fueron estudiados. En la mayoría de los casos, un vehículo principal se asigna a cada agricultor, donde un remolque tirado por tractor, se utiliza para transferir la caña desde el interior del campo hasta la zona de almacenamiento. Los resultados muestran que la eficiencia total del cargador fue del 75% en el caso de camiones de carga en una gran zona de almacenamiento y 81% en el caso de vagones de ferrocarril cargados en una estación. El promedio de la eficiencia total de la cargadora fue de 61% cuando cargó vagones de carga decauvelle distribuidos en varias zonas de almacenamiento dentro de la misma región de producción. La eficiencia de carga de remolques de tractor en el campo fue del 54%. Se observó que se alcanzará la máxima eficiencia si el cargador trabaja el día operativo completo en un área de almacenamiento. La eficiencia de recolección de caña fue variable en condiciones de funcionamiento variables. El porcentaje de la caña con retrasos superiores a 24 horas también fue estimado. Grandes zonas de almacenamiento temporal en las que los camiones son cargados con caña, y estaciones de carga de caña en vagones de ferrocarril pueden representar las condiciones óptimas para el funcionamiento del cargador. El documento analiza la eficacia de la operación del cargador en virtud de una serie de condiciones variables, y en relación con la demora en la entrega de caña. Los resultados destacan el papel de la eficiencia de operación del cargador como un factor determinante de la adopción de cargue mecánico de la caña de azúcar. Se hacen recomendaciones para el buen funcionamiento del cargador de caña.
OPTIMAL USE OF BIOMASS IN AN ISOLATED ENVIRONMENT: CASE STUDY AT MIYAKO ISLAND, JAPAN

By

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KEYWORDS: Biomass, Refinery System, Conversion.

Abstract

This paper briefly outlines an ongoing research project and some research outcomes focusing on sugarcane. Five research topics were identified, namely 1) development of technologies for farmland application of converted biomass from sugarcane molasses such as compost, char, digestive slurry and vinasse, 2) clarification of optimal allocation of biomass and optimal operational conditions for conversion plants, 3) development of groundwater conservation technologies with biomass, mainly focusing on nitrogen, 4) development of technologies for introduction of energy crops and optimal CO₂ gas application to crops, and 5) clarification of favourable conditions for sugar-ethanol by-production systems using greater-biomass sugarcane. Our target biomasses are bagasse and cattle wastes. Five conversion plants, including two pyrolysis, one composting, one bio-gas and one gasification, have already been installed to properly and effectively convert biomass. Farmland application technologies for char and digestive slurry with bagasse have mainly been studied. Secondly, vinasse (bio-ethanol by-product; distilled residue) is another biomass target. We analysed vinasse for return of by-products back to the farmland as a way to achieve sustainability and devote efforts to the application of vinasse to farmland. Of course, safety to crops, the soil and water environment should be confirmed first. Previous experiments revealed vinasse does not have bad impacts on crop growth. Thirdly, we conducted studies to clarify the favourable conditions for introduction of greater biomass sugarcane to develop sugar-ethanol by-production systems. A favourable new variety of sugarcane was previously selected. In addition, a sugar-yield equation for great-biomass sugarcane was developed from observed data.

Introduction

Background

Japan produces an average of about 1 million tonnes of sugarcane each year. Approximately 30% of this is produced on Miyako Island in southern Japan, 1500 km from the capital Tokyo. On this island, agriculture is the major industry followed by tourism. Sugarcane is the major crop on the island with beef cattle breeding as the next most important agricultural activity.

Recently, bio-ethanol production from sugarcane molasses has been supported by the Ministry of Environment (MOE) of Japan as a special project, called ‘E3 Project’ on Miyako Island. The aim was for an integrated project, with sugarcane as the feedstock for ethanol and all by products from all industries would be returned back to the farmland to achieve sustainability. This meant that the by-products of the bio-ethanol manufacturing process were to be applied back on the fields, providing the safety of the materials could be completely assured, i.e. an absence of hazardous materials such as heavy metals, poisonous materials, etc.

Objectives

The Ministry of Agriculture, Forestry and Fisheries (MAFF) of Japan has supported this project named ‘Rural Biomass Research Project, Biomass utilisation model, Cm6000’ for
approximately three years, commencing 2007. In this paper, the framework of the research project and some outcomes and their use are discussed.

**Methodology**

Miyako Island is located in southern Japan, and was selected as the appropriate site for the project. The total area of the island is about 140 km² and the population was approximately 47 000 as of January 2001. Fifty two percent of the area is farmland. The maximum elevation on the island is only 114.6 m, land is geo-physically almost flat and there are no big rivers. The climate is semi-tropical (average temperature 23°C, average humidity 80%) with an annual precipitation of 2400 mm. Most of this precipitation is brought by typhoons and residents suffer from occasional droughts.

Agriculture is the major industry, with sugarcane production alone averaging 300 000 tonnes annually, which accounts for almost 30% of the total Japanese sugarcane production. Tobacco, vegetables and beef are also produced, but almost all other food products are imported from mainland Japan and other islands in the Okinawa region.

The main crops and typical annual biomass production for each of the islands are listed in Table 1.

<table>
<thead>
<tr>
<th>Crop (tonnes)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugarcane</td>
<td>173 100</td>
</tr>
<tr>
<td>Tobacco</td>
<td>1217</td>
</tr>
<tr>
<td>Wax gourd</td>
<td>1127</td>
</tr>
<tr>
<td>Pumpkin</td>
<td>505</td>
</tr>
<tr>
<td>Sweet potato</td>
<td>609</td>
</tr>
<tr>
<td>Mango</td>
<td>217</td>
</tr>
<tr>
<td>Pasture (tonnes)</td>
<td></td>
</tr>
<tr>
<td>Rosegrass</td>
<td>41 138</td>
</tr>
<tr>
<td>Livestock (head)</td>
<td></td>
</tr>
<tr>
<td>Cattle</td>
<td>11 672</td>
</tr>
<tr>
<td>Swine</td>
<td>923</td>
</tr>
<tr>
<td>Chicken</td>
<td>23 513</td>
</tr>
</tbody>
</table>

The soil on the island is almost neutral or alkaline and has a loamy texture (Shimajiri Maji-soil). Maji soil has a high clay content but relatively high permeability (10⁻⁴ cm/s). Because there are almost no mountains, the major water resource is groundwater. The island residents are concerned about the groundwater, not only its quantity but also its quality. Some sub-surface dams were constructed in the 1990s as a national irrigation project to effectively use the groundwater. After construction of sub-surface dams, farmers became enthusiastic about commercial and intensive agriculture.

The outcome of increased availability of water was that farmers attempted to increase productivity and increased the use of chemical fertilisers. This resulted in worsening of the groundwater quality. More recently, many farmers are attempting to reduce the amount of chemical fertilisers they apply and, in addition, they are compelled to properly manage livestock wastes (manure).

The target waste biomass for this project was determined to be sugarcane bagasse and cattle waste, as they are the two types of biomass available in large amounts. According to the Miyakojima Biomass Town Plan (2003), these two biomasses account for about 80% of the total amount of the whole island with a dry weight mass equal to 50 000 tonnes of carbon (C) each year on the island.

**Project strategies**

The Rural Biomass Research Project, Biomass Utilisation Model focused on five research topics, namely:
1) Development of reuse technologies for converted biomass and vinasse from bio-ethanol production,
2) Defining optimal operational conditions for the biomass conversion facilities,
3) Development of technologies for protection of groundwater from contamination with agricultural wastes,
4) Introduction of energy crops taking into consideration sustainability,
5) Determination of installation conditions for larger biomass-sugarcane to develop sugar-ethanol by-production systems.

Pilot (test) scale conversion facilities, namely two pyrolysis systems, one bio-gas system, one gasification system and one composting system, have already been installed on the island (Figure 1). We can obtain energy and materials (charcoal, acid vinegar, anaerobic digestive slurry, compost) after conversion of biomass from these facilities. We hope to apply the materials recovered from the biomass to farmland for sustainable agriculture and to increase productivity. In addition, we hope to develop technology enabling the reuse of the vinasse, a by product of bio-ethanol production. The conversion facilities should be thought as one system. Each conversion facility should link with energy and materials already used. It is necessary for us to operate the conversion ‘systems’ optimally. How shall we achieve this, taking into consideration environmental issues? What is the best way to allocate biomass among the facilities?

On the island, groundwater is a unique water resource and it is crucial for residents that the quality of groundwater is conserved. Chemical fertilisers and cattle wastes are the main sources of nitrogen pollution of groundwater sources on the island (Fujie Rie et al., 2008)). We need to achieve water quality conservation technologies with biomass. For example, charcoal from bagasse can absorb nitrate nitrogen, reported as one of the crucial contaminants of the groundwater. The question is how to reduce contamination of the water with biomass? We need to develop technologies and scenarios.

At this point in time, sugarcane molasses is the only feedstock for bio-ethanol production. We hope to propose additional energy crops to allow the conversion facilities to operate as optimally as possible throughout the year.

From the agricultural side, it is necessary to optimise the soil and water to achieve sustainability. Sweet sorghum, sweet potatoes and cassava are favourable crops we anticipate
introducing. The issue is how to introduce these crops, taking into consideration the sustainability issue of nutrient management based on traditional agricultural machinery systems. Farmers expect additional economic benefits from growing these crops.

An additional consideration is that CO₂ is obtained from various conversion processes. While CO₂ is one GHG (Green House Gas), it is also necessary for crop photosynthesis and production. Is it possible to increase productivity with CO₂ application to crops from the conversion process?

The final consideration is that high-biomass sugarcanes have been developed by our group (National Agricultural Research Center of Kyushu-Okinawa; NARCKY). We hope to use these canes as the basis for a sugar-ethanol production system, with the strategies being developed for the introduction of the system.

This research project has been carried out by researchers at (NIRE), NARCKY, University of Ryukyu, Okinawa Agricultural Research Center, Non Profitable Organisations, Semi-tropic Biomass Use Research Center and Asahi Breweries Ltd. as well as scientists from various other research fields. In the NPOs, many members are from private companies in Japan. We have been exchanging various kinds of information among central (Ministry of Cabinet) and provincial governments (namely Prefecture of Okinawa and Miyakojima City). This research project is achieved by industries, institutes and governments.

**Main research outcomes**

The project is now over half way through its life, and some outcomes have already been reported in domestic publications, as well as at various domestic and international technical meetings. Outcomes to date have included:

**Nitrate nitrogen loads from chemical fertilisers and cattle wastes (Fujie Rie et al., 2008)**

Nitrate nitrogen is a major contributor to groundwater contamination on the island. The main agricultural nitrogen resources are chemical fertiliser (applied to farmland) and improper cattle waste management (Miyakojima Biomass Town Paper).

![Fig. 2—Nitrate nitrogen loads at Sunagawa groundwater-basin in 1977, 1994 and 2005, respectively (Fujie Rie et al., 2008)](image)

Parameters relating to cropping and agriculture in the Sunagawa Groundwater Basin on the Island were defined and entered into a database using GIS. A DeNitrification and DeComposition (DNDC) model was used to estimate the leached nitrate nitrogen from the soil associated with each crop. The estimates were used in the database to estimate the amount of nitrate nitrogen leached throughout the basin. The cropping conditions for each year studied were entered in a database, using GIS to properly identify changes.

Figure 2 shows the calculated results of leached nitrate nitrogen in 1977, 1994 and 2005, respectively. The estimations indicate that the leached nitrate nitrogen fluctuates with changes in land use and agricultural parameters such as chemical fertiliser application amount and type of crop.
Calculations of nitrogen concentrations in percolated water indicate that nitrogen can quantitatively explain the changes in groundwater quality. We can, therefore, quantify the contamination load from agriculture.

In the future, trial calculations of leached nitrate nitrogen based on various cropping conditions and agricultural performances will be carried out and applied as a basin-level management method to manage agricultural activities while considering groundwater conservation.

1) **Impacts of farmland application of converted biomass**

Anaerobic digested slurry and charcoal from bagasse were applied to farmland to assess the impact on crop growth, which was assessed from both plots and field lysimeters (Chen Yan and Shinogi Yoshiyuki, 2007; Chen Yan et al., 2007; Chen Yan and Shinogi Yoshiyuki, 2005).

Application of charcoal from bagasse increased the production of sugarcane and other vegetables. It improved the root-zone soil physical properties by improving soil-water holding capacity and permeability, as well as other parameters, with the improvements continuing for at least 55 months after application. In addition, charcoal absorbed nitrate nitrogen and application of charcoal from bagasse reduced nitrate nitrogen loads to the groundwater. Therefore, charcoal from bagasse may be used to reduce the bad impact of agriculture.

In other trials, digestive slurry reduces the amount of chemical fertiliser that needs to be applied by about 30%.

**Development of vinasse use technology**

<table>
<thead>
<tr>
<th>pH</th>
<th>Colour</th>
<th>BOD</th>
<th>COD_{bio}</th>
<th>COD_{cr}</th>
<th>TOC</th>
<th>K⁺</th>
<th>T-N</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.28</td>
<td>44 000</td>
<td>50 900</td>
<td>81 900</td>
<td>172 000</td>
<td>55 400</td>
<td>17 000</td>
<td>1976</td>
<td>120</td>
</tr>
</tbody>
</table>

The main characteristics of vinasse from sugarcane molasses are reported to be 1) high organic matter, 2) high COD and BOD, 3) black-colour, 4) highly acidic. The basic characteristics are shown in Table 2. Sugarcane molasses is produced from just sugarcane so there are not likely to be hazardous materials. Preliminary tests, including incubation tests, were carried out to assess the implications of farmland application. The results indicated no negative impacts on crop production. Providing the impacts on the environment, mainly groundwater contamination are monitored, it may be possible to apply vinasse to farmland. Because of the high viscosity of vinasse, it is believed that it does not percolate deeply, allowing effective use by plants. Further research is needed to confirm this.

**Other kinds of outcomes on sugarcane**

High-biomass sugarcane was developed by our group, and initial larger scale trials have been carried out. Indications are that these sugarcanes have almost the same Brix (13–16%) as other great-biomass canes, and similar to traditional commercial sucrose varieties. These sugarcanes not only produce more sugar but also higher biomass.

In addition to establishing a sugar-ethanol by-production system, our group developed an equation called Commercial Cane Sugar at n-times Crystallisation (CCSₙ) from data collected in the laboratory. This enables us to easily estimate CCS.

**Perspectives and conclusions**

Research outcomes have been presented locally, nationally and internationally. In addition, our research projects aim to achieve real action plans and outcomes. We therefore actively communicate information to all levels of government. How can these research outcomes be utilised and, based on them, how will the residents proceed with actual action plans? The most important thing for us is the creation of real business models that use biomass on the island.

In this fiscal year, we hope to publish a manual for the application of converted biomass to farmland. In addition, we expect to transfer some research outputs to existing technologies. For
example, development of CO$_2$ application technology from the conversion facilities is expected. Proper assessment of the impacts of biomass use should also be completed. To accomplish this, integrated evaluation technologies based on the actual data and calculation tools such as Life Cycle Assessment (LCA) are necessary. Further research is required and special efforts made to approach and achieve these goals.

REFERENCES


UTILISATION OPTIMALE DE LA BIOMASSE DANS UN ENVIRONEMENT ISOLE: ETUDE DE CAS DANS L’ILE DE MIYAKO, JAPON

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MOTS CLES: Biomasse, Système de Raffinerie, Conversion.

Résumé
Ce papier décrit brièvement un projet de recherche en cours et quelques résultats de recherches sur la canne à sucre. Cinq sujets de recherche ont été identifiés, notamment 1) le développement de technologies pour l’application biomasses converties de la mélassé de canne à sucre, tels le compost, la cendre, le lisier et la vinasse sur les terres cultivées. 2) La clarification de l’allocation optimale de biomasse et des conditions d’opération optimales pour les usine de conversion. 3) Développement de technologies de conservation de l’eau souterraine avec la biomasse, avec emphase sur l’azote. 4) Développement de technologies pour l’introduction des cultures d’énergie et d’application optimale de CO₂ gazeuse aux cultures. 5) Clarification des conditions favorables pour la production simultanée de sucre et d’éthanol en utilisant la canne à sucre a fort biomasse. Nos biomasses cibles sont la bagasse et les déchets d’élevage. Cinq usines de conversion, incluant deux par pyrolyse, une de compostage, une de biogaz et une de gazéification ont déjà été installées afin de convertir correctement et efficacement la biomasse. Deuxièmement, la vinasse (sous-produit de bio-éthanol, résidu de distillation) est une autre cible de biomasse. Nous avons analysé la vinasse pour le retour des sous-produits à la terre cultivée comme un moyen d’atteindre la durabilité et avons consacré nos efforts à l’application de la vinasse à la terre arable. Bien sûr, la sécurité aux cultures, à l’environnement du sol et de l’eau doivent d’abord être confirmés. Les essais précédents ont démontré que la vinasse n’a pas d’effet négatif sur le développement de la culture. Troisièmement, nous avons mené des études afin de clarifier les conditions favorables pour l’introduction de canne à sucre à fort biomasse pour développer les systèmes de production sucre-éthanol. Une nouvelle variété de canne à sucre favorable fut préalablement sélectionnée. De plus, une équation de rendement sucre pour la canne à fort biomasse fut développé à partir des données observées.
EL USO ÓPTIMO DE LA BIOMASA EN UN ENTORNO AISLADO: 
ESTUDIO DE CASO EN LA ISLA DE MIYAKO, JAPÓN

Por

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PALABRAS CLAVE: Biomasa, Sistema de Refinería, Conversión.

Resumen

ESTE DOCUMENTO describe brevemente un proyecto de investigación en curso y algunos resultados de investigación en caña de azúcar. Fueron identificados cinco temas de investigación, a saber: 1) desarrollo de tecnologías para la aplicación en tierras agrícolas de biomasa procesada a partir de melazas de caña de azúcar tales como: compost, char, purines digestivos y vinazas, 2) definir la localización y condiciones operacionales óptimas de las plantas de conversión de biomasa, 3) desarrollo de tecnologías de conservación de aguas subterráneas basadas el uso de biomasa y enfocadas principalmente en nitrógeno, 4) desarrollo de tecnologías para la introducción de cultivos energéticos y aplicación óptima de CO2 gaseoso a los cultivos, y 5) definición de las condiciones adecuadas para que los sistemas de producción dual azúcar-etanol usen una alta proporción de la biomasa de la caña de azúcar. Nuestra biomasa objetivo son el bagazo y los excrementos vacunos. Cinco plantas de conversión, entre ellas dos de pirólisis, una de compostaje, una de bio-gas y una de gasificación, ya han sido instaladas para realizar una efectiva y apropiada conversión de la biomasa. Se han estudiado principalmente tecnologías de aplicación de char y purines digestivos con bagazo a tierras agrícolas. El segundo lugar lo ocupa la vinaza (sub-producto del bio-etanol; residuo de la destilación) que es otro objetivo de uso de biomasa. Analizamos el retorno de la vinaza a las tierras de cultivo como una forma de lograr la sostenibilidad y dedicar esfuerzos a su aplicación en tierras agrícolas. Por supuesto, la seguridad para los cultivos, para el ambiente edáfico y acuático debe ser confirmada primero. Experimentos anteriores revelaron que la vinaza no tiene impactos negativos en el crecimiento de los cultivos. En tercer lugar, llevamos a cabo estudios para caracterizar las condiciones favorables para la introducción de caña de azúcar con mayor producción de biomasa para desarrollar sistemas duales para la elaboración de azúcar-etanol de caña. Previamente se seleccionó una nueva variedad de caña de azúcar. Adicionalmente, a partir de datos observados se desarrolló una ecuación de rendimiento de azúcar para caña de azúcar de alta producción de biomasa.
SOIL MOISTURE GROUPS FOR SUGARCANE MANAGEMENT

By

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KEYWORDS: Soil, Moisture, Drainage, Permeability, Cane Management.

Abstract

CANE YIELD in Colombia is normally lower after wet years due to increased damage associated with harvest and the difficulty of post-harvest cultivation. The magnitude of the problem is impacted on by soil characteristics. To identify fields or areas requiring emphasis on irrigation or drainage and for the development of agronomic management packages, soil moisture management groups have been developed. The definition of soil moisture management groups is based on the annual balance between precipitation at 75% frequency level and soil permeability. The precipitation records from the sugarcane automatic weather network and the information from a recent detailed study of the soils of the Cauca River Valley of Colombia have been combined using the geographical information system to generate the spatial distribution of the soil moisture groups. Five groups were defined on the basis of the expected annual excess or deficit of water for sugarcane: A first group with a water deficit, a second group with an excess of water ranging from 0 to 200 mm/year, a third group with an excess of 200 to 400 mm/year, a fourth group with an excess of 400 to 600 mm/year and a fifth group with an excess of water greater than 600 mm/year. These moisture groups have been used as a backbone for the agro-ecological zoning system of the sugarcane in the Cauca Valley of Colombia. The Colombian sugar industry is committed to use a site specific agriculture approach based on the combination of the production factors on each cane field.

Introduction

The productivity of the Colombian sugar industry largely depends upon climatic conditions prevalent during crop establishment, harvesting and the first stage of ratoon crop development. Murrell and Childs (2000) indicated that it is necessary to identify the factors limiting production that can be controlled.

Critical values according to predominant environmental conditions should also be set. In wet years, those areas with heavy soils and low infiltration capacity are prone to water logging and cultural practices can not be executed on time; therefore, the expected cane yield is low.

Excessive moisture produces anaerobic conditions in the soil, reduced root respiration, demineralisation of nitrogen and poor crop growth affecting adversely the final cane and sugar yield. In flooded terrain or with high water table, the number of working days for land preparation or ratooning practices is reduced. If a crop is not established in time, it may result in a crop with increased production costs and reduced yield.

Experiments conducted by Cenicaña (1991) using percolating type lysimeters depicted a yield reduction of 35 t/ha when the static water table was maintained at 70 cm below the soil surface. If soil moisture excess occurs during land preparation, planting or harvesting, all these practices should be delayed; otherwise soil compaction, stool damage and poor cane germination/regrowth are expected, increasing production cost if replanting is necessary.
A macro analysis of cane and sugar production in the Cauca River Valley (Cenicaña, 1996) for the period 1991 to 1995 showed that cane production in most of the sugar mills in the years 1994 and 1995 were negatively affected by high precipitations that occurred during the three first months of crop development, or by the rainfall events during the last month of the previous crop cycle. When rainfall events happened during the first stage of crop development, fertilisation and/or ratooning tasks could not be executed on time or efficiently. Intensive rainfall events during the harvest of the previous crop resulted in excessive soil moisture that hampered the traffic of the harvesting machinery, inducing soil compaction and cane stool damage.

According to commercial production data from the Cauca River Valley in Colombia, it is clear that dry years are ideal for cane and sugar production. This is a result of both the availability and adequacy of the existing irrigation infrastructure, and the opportunity for more efficient and timely execution of cultural practices under dry conditions. Harvesting in wet conditions usually results in fields affected by direct stool damage, soil compaction and surface deformation. In some cases, field damage is so serious that remedial cultivation is in order to maintain crop productivity, but persistent rainfall events cause postponement of the remedial practices, resulting in idle or ‘forced fallow’ fields.

Weather conditions which make it difficult to execute cultural practices or harvesting due to excessive soil moisture have become more common, especially with the increasing presence of the El Niño phenomenon. It is therefore necessary to adopt strategies for optimum management of the cane fields under these conditions.

This study was undertaken to group the soils of the Cauca River Valley according to their ability to transmit water after a heavy rainfall event, and subsequently generate management guidelines to decrease the impact of excessive soil moisture on cane production.

**Methodology**

Field observations of the interaction between soil permeability and rainfall demonstrated that a very permeable soil will dry out quite rapidly after a heavy rainfall event, due to the high water transmitting or infiltration capacity. This characteristic allows the execution of cultural practices, or entry to the field with harvesting machinery a few hours after the rainfall. On the other hand, low permeability soils will remain wet after a light rainfall event, and there is a possibility of surface flooding after intense rainfall.

Initially, the reasoning used to develop soil moisture groups was based on the balance between the expected annual rainfall at 75% probability level, and the total annual evapo-transpiration (ET) calculated using boom stage values.

The amount of annual deficit or excess of water was established and compared with the permeability of the soil according to the matrix presented in Table 1. Six regions were demarcated within the matrix that correspond to six soil moisture groups identified as H0, H1, H2, H3, H4 and H5.

<table>
<thead>
<tr>
<th>Water excess (mm/year)</th>
<th>Soil permeability (m/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low (&lt; 0.5)</td>
</tr>
<tr>
<td>Very high (&gt; 600)</td>
<td>H5</td>
</tr>
<tr>
<td>High (400–600)</td>
<td>H4</td>
</tr>
<tr>
<td>Medium (200–400)</td>
<td>H3</td>
</tr>
<tr>
<td>Low 0–200)</td>
<td>H2</td>
</tr>
<tr>
<td>Deficit (&lt; 0)</td>
<td>H1</td>
</tr>
</tbody>
</table>

Table 1—Definition of soil moisture group regions based on the interaction between water excesses and soil permeability.
Field inspections of the prevailing soil moisture conditions at 84 observation sites distributed along and across the Cauca River Valley indicated the necessity to include other parameters. The parameters selected modified the impact of soil moisture on plant growth, and included: land slope, depth to the water table, soil colour and the presence of artificial drainage installations.

In order to adjust the soil moisture groups according to prevalent local conditions of the cane fields, a logic-based process was developed to adjust the group number according to the severity of the drainage problem induced by each individual factor. A computer program was then developed. This program is available on Cenicaña’s web site (www.cenicana.org) and is used to verify or adjust the predominant soil moisture groups based on site specific conditions.

The main purpose of the soil grouping strategy is to generate basic guidelines to mitigate the impact of soil moisture on crop production. The most basic recommendations compiled for each soil moisture group are:

**H0: Water deficit group**
This group includes zones where there is water deficit and the permeability of the soil ranges from medium to high. It is very likely that salts accumulate in the soil profile, making it necessary to avoid the presence of high water tables. Artificial drainage installation could be required for saline or sodic soil reclamation. Irrigation is essential and a salt leaching fraction should be applied to avoid soil salinity build up.

**H1: Adequate water supply group**
This group consists of those areas where the annual water excess is less than 200 mm/year. Rainfall is sufficient to supply the crop water demand and the soils have medium to high permeability.

Rainfall distribution is not uniform and it is possible to observe some water ponding due to the flat slope of the terrain when the soils have low permeability. Precision land levelling and a minimum hilling up (<10 cm) to facilitate surface water runoff at the bottom of the rows during the rainy periods are advised.

**H2: Low excess water group**
The level of excess soil moisture ranges between 200 and 400 mm/year in soils which have medium to high permeability, as well as soils with low permeability with lower soil moisture excess (<200 mm/year). It is necessary to provide adequate field conditions such as precision land levelling, medium hilling up (10 to 15 cm), and adequate infrastructure for drainage.

**H3: Medium excess water group**
This group covers areas with water excess ranging between 400 to 600 mm/year and soil with medium to high permeability. Soils with low permeability but lower soil moisture excess (200 to 400 mm/year) were also included.

This group requires more intensive work for excess water removal, including land levelling, deep open canal collectors, removal of run off water, if possible, excess water tolerant varieties, application of an extra amount of nitrogen, high hilling up (15 to 20 cm).

**H4: High excess water group**
This group covers areas with water excess above 400 mm/year, with soils of low or high permeability, clay soils and predominance of flat slopes. The furrow length should be less than 120 m, drainage tubing installations combined with the presence of mole drains, open and deep drainage collectors and drainage pumping stations at places where gravity outlets are not available.

High hilling up is considered essential, top of row planting, varieties tolerant to excess water, application of extra nitrogen and harvesting in dry periods.
H5: Very high excess water group

Areas with water excess above 600 mm/year with flat terrain and clay soils with low to medium permeability. In this group, precision land levelling is a must and furrows should be shorter than 100 m. Drainage tubing installations combined with the presence of mole drains, open and deep drainage collectors and drainage pumping stations at places where gravity outlets are not available are also necessary. High hilling up is considered essential, along with top of row planting. Varieties tolerant to excess water and the application of extra nitrogen is recommended. Manual harvesting during dry periods is recommended.

Results and discussion

The information of the soil moisture groups for the Cauca River Valley region was fed into the Geographic Information System (GIS) to obtain maps depicting the spatial distribution and area covered by each soil moisture group (Figure 1).

![Fig. 1—Spatial distribution of the soil moisture groups in the Cauca River Valley of Colombia.](image)

Most of the cultivated area within the sugarcane zone belongs to the moisture groups H0 and H1. This can be considered as a dry zone amounting to 119 025 ha, (58%) of the total of 203 778 ha of land currently planted in the valley. While all the sugar estates have cultivated areas in the dry zone, the agricultural lands of Manuelita, Providencia and Mayaguez sugar estates, which are located in the south central part of the valley, are predominantly in the H0 and H1 groups.
In these areas, in dry years, it is necessary to apply up to six or seven irrigation events per crop cycle of 13 months.

The areas of the soil moisture groups H2 and H3 can be considered a semidry zone. Most of the cane area belongs to Cauca, Cabaña, Castilla and Riopaila sugar estates in this zone, and the total area adds up to 64 300 ha, which is 32% of the total agricultural area. In this zone, there is an annual water excess ranging between 200 to 400 mm of water in the low and medium permeability soils or with a water excess of 600 mm/year in areas with high permeability soils. This semidry zone requires the installation of more artificial drainage infrastructure.

The wettest zone of the valley (H4 and H5 groups) is concentrated in the northern and southern extremes of the Cauca River Valley covering an area of 19 410 ha (10% of the total area); however, this comprises a significant portion of Risaralda, Castilla, Cabaña and Cauca sugar estates. In the wet zone, the annual water excess is above 600 mm/year.

Planting, cultivation and harvesting of the cane is difficult due to high precipitation which in general is above 2000 mm/year. In this region, it is necessary to emphasise drainage development, precision land levelling and a short furrow length. Cane and sugar yields in this area are in general low due to the negative effects of the excess moisture on crop growth and maturity, and the interference with the execution of good cultural practices.

Conclusions

The soil moisture groups presented herein have become an important tool for crop management, selection of experiment sites, identification of the best niches for the new cane varieties, generation of site specific agronomic management packages and, combined with Cenicaña’s soil management groups, have resulted in the agro-ecological zoning system for the sugarcane in the Cauca River Valley of Colombia.

The agro-ecological zones developed by Cenicaña (Carbonell et al., 2001), were presented to the sugar cane industry in 2001 and it has been well accepted by the sugar estates, and individual cane growers; it is a primary input tool for research purposes and for crop management.

REFERENCES


**GROUPEMENTS D’HUMIDITE DU SOL POUR LA GESTION DE LA CANNE**

Par

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**MOTS CLES:** Sol, Humidité, Drainage, Perméabilité, Gestion de la Cane.

**Résumé**

LE RENDEMENT canne en Colombie est normalement plus bas après les années humides suite à l’augmentation des dégâts associés à la récolte and les difficultés des opérations poste-récolte. Les caractéristiques du sol ont un effet sur l’importance du problème. Des groupements de gestion de l’humidité du sol ont été constitués afin d’identifier les champs ou zones nécessitant une emphase sur l’irrigation ou le drainage et pour le développement de packages de gestion agromonique. La définition des groupements de gestion de l’humidité du sol est basée sur la balance annuelle entre les pluies à 75% de niveau de fréquence et la perméabilité du sol. Les relevés de pluie provenant du réseau climatique automatique de la canne à sucre et l’information provenant d’une récente étude détaillée des sols de la vallée de la rivière Cauca de Colombie ont été combinés avec un système d’information géographique pour générer la distribution spatiale des groupements d’humidité. Six groupements ont été définis sur la base de l’excédent ou déficit hydrique annuels attendus pour la canne à sucre : un premier groupement avec un déficit, un second avec un excédent d’eau entre 0 et 200 mm/an, un troisième avec un excédent d’eau entre 200 et 400 mm/an, un quatrième avec un excédent d’eau entre 400 et 600 mm/an et un cinquième avec un excédent d’eau supérieur à 600 mm/an. Ces groupements d’humidité furent utilisés comme ossature pour le zonage du système agro-écologique dans la vallée de Cauca en Colombie. L’industrie sucrière Colombienne est commise à utiliser une approche spécifique de site, basée sur la combinaison des facteurs de production de chaque champ de canne.
GRUPOS DE HUMEDAD PARA EL MANEJO DE LA CAÑA DE AZÚCAR

Por

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PALABRAS CLAVE: Suelo, Humedad, Drenaje, Permeabilidad, Manejo de la Caña.

Resumen

EN GENERAL, la producción de caña en Colombia disminuye en los años de mayor precipitación debido a los daños asociados con la cosecha y la dificultad para realizar labores de cultivo después de la cosecha. La magnitud del problema se agudiza de acuerdo con las características del suelo. Para identificar los campos o áreas que requieren énfasis en riego o drenaje y para definir paquetes de manejo agronómico específico por sitio, se desarrollaron los grupos de humedad del suelo, cuya definición se basa en el balance entre la precipitación anual calculada con el 75% de probabilidad y la permeabilidad del suelo. Los registros de precipitación de la red meteorológica automática de la caña de azúcar y la información extractada del reciente estudio detallado de suelos del valle del río Cauca en Colombia se han combinado utilizando el sistema de información geográfico para generar la distribución espacial de los grupos de la humedad del suelo. Se definieron seis grupos de humedad sobre la base del exceso o déficit de humedad anual esperado para la caña de azúcar: El primer grupo de humedad es el que presenta algún déficit de agua para el cultivo de la caña, en el segundo grupo ocurren unos excesos de agua que van desde 0 hasta 200 mm/año, en el tercer grupo los excesos oscilan entre 200 a 400 mm/año, en el cuarto grupo los excesos son de 400 a 600 mm/año y en el quinto grupo los excesos de agua superan los 600 mm/año. Estos grupos de humedad han sido utilizados como base para definir el sistema de zonificación agro-ecológica de la caña de azúcar en el Valle geográfico de río Cauca, Colombia. La agroindustria de la caña en Colombia se ha comprometido a utilizar el enfoque de agricultura específica por sitio basada en la combinación de los factores de producción que intervienen en cada campo sembrado en caña.
DRIP IRRIGATION FREQUENCY FOR SUGARCANE IN THE TROPICS

By

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KEYWORDS: Drip Irrigation, Irrigation Schedule, Water Saving, Sugarcane Production, Colombia.

Abstract
Drip Irrigation was a system initially developed for desert areas where the sandy soils have low water retention capacity and rainfall is limited. In the Cauca river valley, located in south-western Colombia, soils have a high water retention capacity and frequent irrigation results in excess moisture and poor root development, which affects crop development. The frequent application of water in the sugarcane soils of the Cauca River Valley results in excess soil water and little use of natural precipitation. The current study was conducted at the Malimbi Sugarcane Plantation, located in the driest area of the Cauca River Valley where annual precipitation is below 800 mm and soils are loamy to clayey in texture. The effect of irrigation frequency (daily, twice a week, weekly) was studied in drip-irrigated plots. A gravity irrigation system was used as check. In three consecutive cuts (plant crop and two ratoons), sugarcane production in drip-irrigated plots was 160 t/ha with daily irrigation (483 mm water applied), 165 t/ha when irrigated twice a week (356 mm water applied), and 166 t/ha when irrigated weekly (264 mm water applied). Gravity-irrigated cane produced 157 t/ha, with an average of 465 mm water applied. Average precipitation during the three cuts reached 984 mm. Results highlight the importance of taking advantage not only of the soil’s capacity to store available water but also of actual precipitation, scheduling the weekly drip irrigation of sugarcane fields in the Cauca River Valley without adversely affecting cane production.

Introduction
Given the shortage of water for irrigation and the increasing irrigation fees in the Cauca River Valley, located in south-western Colombia, sugarcane producers are now considering the possibility of investing in drip irrigation. They are, however, concerned because, in the past, they have had problems with hoses and emitters clogging up because of the build-up of iron and manganese (Franco et al., 1984) and because of the severe damage to hoses caused by harvest equipment (Cenicaña, 1984).

In parts of the sugarcane production areas where annual precipitation is below 1000 mm, the water supply is from deep wells drilled more than 15 years ago. Current flows from these wells range between 40–50 L/sec. These low flows are not sufficient to apply gravity irrigation, which uses a flow of more than 60 L/s. The dilemma arises whether to invest in the building of new wells that could yield more than 60 L/s, at a cost of US $125 000 each, or to invest in drip irrigation to take advantage of the low flow of existing wells.

In 2003, a preliminary drip irrigation trial was conducted at the La Josepilla Sugarcane Plantation, located in a low-rainfall area (700 mm/year) of the Cauca River Valley where irrigation...
requirements are high and the availability of irrigation water is low (wells producing 40 L/sec). Trials consisted of three planting systems (two with double furrows and one with single furrows), two distances between emitters (0.5 and 0.7 m), and two emitter flows (1.2 and 1.6 L/h). While the water volumes used in drip irrigation were 48% less than those used in gravity irrigation, the production of drip-irrigated cane was 20–60 t/ha higher than that of furrow-irrigated cane. The results of the preliminary trial carried out at the La Josepilla Sugarcane Plantation cannot be extrapolated to other areas because of the many mixed variables including planting configuration, spacing between emitters, emitter flows, fertiliser application rates and varieties. Therefore, in 2005, a new collaborative experiment was carried out by Cenicaña and the Malimbú Sugarcane Plantation, using emitters spaced at 0.5 m with a flow of 1.6 L/hour, three irrigation frequencies, and two planting arrangements (double and single furrows).

Materials and methods

The experimental site is representative of the driest area of the Cauca River Valley, with an average annual precipitation of 800 mm and two soil types: Rio Paila (Fluventic Haplustolls, coarse loam texture) and Manuelita (Fluventic Haplustolls, fine loam texture), both characterised as being deep, well drained, and very fertile.

A split-plot experimental design was used with the irrigation frequency treatment assigned to the main plot and the spacing between furrows to the subplot.

The following irrigation frequencies were evaluated: (1) daily; (2) twice a week; and (3) weekly. Spacing between furrows was as follows:

1. single furrow at 1.75 m;
2. double furrow with 2.6 m between pairs and 0.6 m between furrows; and
3. double furrow with 2.4 m between pairs and 0.4 m between furrows.

The check was a gravity-irrigated lot planted to sugarcane variety CC 85-92 spaced at 1.75 m. Irrigation was scheduled using the water balance method, with a K factor of 0.3 when the crop was 2–4 months old and one of 0.7 when the crop was 4–10 months old.

Forty soil samples were collected using an auger up to a depth of 1.2 m. To describe the soil profile, two sampling pits were dug and samples were collected to determine the soil’s chemical and physical properties. Based on the chemical analysis of the soil, the recommended fertilisation for the plant crop was 80 kg N, 90 kg K₂O, and 7.5 kg Fe/ha.

Once soil preparation activities were completed, the drip irrigation system was installed. The system consists of a filter-and-control station where water is taken directly from a deep well and passed through a hydro cyclone filter, a gravel filter, and two ring filters. Fertilisation equipment consists of a 1.9 cm Venturi injector with a regulator and three 2000-L plastic tanks to mix the soluble fertilisers (N, P, K). Four control valves were installed in the field. These valves can be controlled by hand from the station and also by an automatic timer. The principal pipeline consists of a PVC tube, 10 and 8 cm in diameter, to which lateral hoses (internal diameter of 1.6 cm) are connected after. Emitters are located along these lateral hoses with a water flow of 1.6 L/hour.

The crop was planted on 3 August 2005 and, because the drip irrigation system had not yet been fully installed, sprinkler irrigation was performed immediately, applying a 45-mm water sheet, to enhance crop germination. During crop development, agronomic evaluations were made at 2, 4, 6, 8, and 10 months and then again at harvest.

Results and discussion

In the plant crop, drip-irrigated cane (variety CC 85-92) produced, on average, 162 t/ha, whereas the gravity-irrigated check produced 154 t/ha, a difference of 8 t/ha in favour of drip irrigation (Table 1). As previously noted, in the drip irrigation experimental field, the first germination irrigation was applied by sprinkling because at that time the drip irrigation system had not yet been fully installed. The initial population in the drip-irrigated field was lower than that of...
the gravity-irrigated check because the germination irrigation by sprinkling was deficient—several areas presented water deficit and, at other sites, the water swept the seed away because of disconnections in the pipeline.

No significant differences were observed in other production indices—sugar yield, sugar production, tonnes of cane per hectare-month (TCHM), and tonnes of sugar per hectare-month (TAHM)—in relation to the irrigation system (drip versus gravity).

<table>
<thead>
<tr>
<th>Table 1—Production of cane variety CC 85-92 on the Malimbú Sugarcane Plantation, located in the Cauca River Valley, South-western Colombia, using two different irrigation systems.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Production index</strong></td>
</tr>
<tr>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td>Cane production (t/ha)</td>
</tr>
<tr>
<td>Sugar yield (%)</td>
</tr>
<tr>
<td>Sugar production (t/ha)</td>
</tr>
<tr>
<td>Harvest age (months)</td>
</tr>
<tr>
<td>TCHM</td>
</tr>
<tr>
<td>TAHM</td>
</tr>
<tr>
<td>Total water applied (mm)*</td>
</tr>
<tr>
<td>Total precipitation</td>
</tr>
</tbody>
</table>

The distribution of monthly precipitation between months two and nine of the cane crop (Figure 1) was satisfactory and, as a result, only one event of gravity irrigation (148 mm) was required during crop growth.

The number of irrigations in the case of drip irrigation was high: 63 for daily irrigation and 16 for twice-a-week irrigation. In the case of drip irrigation applied daily, the total water application was 319 mm, which was more than double (115%) that of gravity irrigation whereas, with the twice-a-week frequency, the total water application was 207 mm, 40% more than with gravity.
irrigation. In the case of the ratoons, the decision was made to test weekly drip irrigation to take advantage of the rains and the soil’s water retention capacity.

In plant crops, the application of fertilisers using the drip irrigation system (fertigation) was carried out regardless of the irrigation schedule, which increased water consumption between 12% and 18%. For the first ratoon, fertilisation was synchronised with the drip irrigation schedule to avoid additional water use.

In the first ratoon, grown between 22 September 2006 and 2 October 2007 (12.3 months), the yield of drip-irrigated cane variety CC 85-92 was, on average, 147 t/ha, whereas the gravity-irrigated check yielded 150 t/ha, indicating that there was no significant differences in yield between drip irrigation and gravity irrigation (Table 1). Regarding the other production indexes (sugar yield, sugar production, TCHM, and TAHM), no significant differences were observed in relation to the irrigation system (drip versus gravity). It should be mentioned, however, that the skids of the lifters caused severe damage to the stools in drip-irrigated fields during the harvesting of the plant crop, especially in double-furrow planting. As a result, there was extensive replanting to replace the cane population.

The monthly precipitation during the first ratoon was deficient between 4–6 months and 8–10 months after planting (Figure 2). It was therefore necessary to apply five gravity irrigations for a total water application of 690 mm, whereas the total water application in the case of drip irrigation was 511 mm in the daily or conventional irrigation, 382 mm in the twice-a-week irrigation, and 334 mm in the weekly irrigation, which represents a saving of water of 26% in the daily frequency, 45% in the twice-a-week frequency, and 52% in the weekly frequency as compared with gravity irrigation.

![Fig. 2—Water conditions of the first ratoon crop of sugarcane variety CC 84-92 during a drip irrigation experiment carried out at the Malimbú Sugarcane Plantation, located in south-western Colombia.](image)

The second ratoon was grown on 2 October 2007 and harvested at 14.4 months (12 December 2008), in the case of the drip-irrigated cane, and at 16.2 months (7 February 2009) in the gravity-irrigated check. The yield of drip-irrigated cane variety CC 85-92 was, on average, 190 t/ha,
whereas the gravity-irrigated check yielded 168 t/ha, a difference of 22 t/ha (13%) in favour of drip irrigation (Table 1). Sugar yield (11.81%) in drip-irrigated fields was slightly lower than in gravity-irrigated fields (12.4%), whereas sugar production was higher (22.4 t/ha versus 20.8 t/ha). Finally, the monthly production of drip-irrigated cane (13.2 t/ha per month) was higher than that of gravity-irrigated cane (10.4 t/ha per month); monthly sugar production under drip irrigation (1.56 t/ha per month) was also higher than under gravity irrigation (1.29 t/ha per month).

Precipitation during the second ratoon was 1345 mm, surpassing by 50% the average value for the area and well distributed throughout the crop cycle (Figure 3). Plantation administrators decided to apply irrigation up to 12 months after planting, taking into account the state mill’s announcement to harvest between 14 and 15 months old because of delays in the harvest schedule. The gravity-irrigated check only required two irrigations, one at 10 and the other at 12 months, for a total water application of 240 mm. In drip irrigation, the total water application was 365 mm in daily or conventional irrigation, 329 mm in the twice-a-week irrigation, and 194 mm in the weekly irrigation. This means that there was a 19% saving in the amount of water used in the weekly drip irrigation alone as compared with gravity irrigation.

![Fig. 3—Water conditions of the second ratoon of sugarcane variety CC 84-92 during a drip irrigation experiment carried out at the Malimbú Sugarcane Plantation, located in south-western Colombia](image)

The average yield of drip-irrigated cane variety CC 85-92 for the three cuts was 166 t/ha, whereas the gravity-irrigated check yielded 157 t/ha, a 6% difference in favour of the former (Table 1). No difference was observed in sugar yield between drip irrigation (12.4%) and gravity irrigation (12.6%), whereas the sugar production of drip-irrigated cane was 20.6 t/ha as compared with gravity-irrigated cane with 19.8 t/ha, a 4% difference.

The TCHM index was 12.2 in the case of drip irrigation compared with 11.1 in the case of gravity irrigation (a 10% difference); the TAHM was 1.51 in drip irrigation and 1.39 in gravity irrigation, an 8% difference. In two of the three cuts (plant crop and the second ratoon), the monthly precipitation was above average for the area and only one gravity irrigation event (148 mm) was required in the plant crop and two gravity irrigations in the second ratoon during the period of crop growth. From 5 to 7 gravity irrigations are normally required in the area where the experiment was conducted. The average water application per crop cycle was 465 mm in gravity irrigation and 264 mm in weekly drip irrigation, representing a saving of 201 mm (43%) in the case of the latter.

Regarding the frequency of drip irrigation, no significant differences were observed in cane and sugar production over the three cuts (Table 2). However, significant differences were detected
regarding the amounts of water applied per crop cycle, especially in the first and second ratoons. In the first ratoon, these amounts were 511 mm for daily irrigation, 382 mm for twice-a-week irrigation, and 334 mm for weekly irrigation. In the second ratoon, the total water application was 365 mm for the daily drip irrigation, 329 mm for the twice-a-week irrigation, and 194 mm for the weekly irrigation. This indicates that, under these environmental conditions, drip irrigation should be scheduled based on the water balance and applied at a weekly frequency to obtain a significant saving in the amount of water used (46%) with respect to daily irrigation by taking advantage of the precipitation and the water storage capacity of soils in the Cauca River Valley.

Table 2—Production of cane variety CC 85-92 on the Malimbú Sugarcane Plantation, located in the Cauca River Valley, Southwestern Colombia, using three frequencies of drip irrigation.

<table>
<thead>
<tr>
<th>Production index</th>
<th>Plant crop</th>
<th>First ratoon</th>
<th>Second ratoon</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Daily</td>
<td>Twice a week</td>
<td>Daily</td>
<td>Twice a week</td>
</tr>
<tr>
<td>Cane production (t/ha)</td>
<td>158 162</td>
<td>142 145 146</td>
<td>180 187 184</td>
<td>160  165  165</td>
</tr>
<tr>
<td>Sugar yield (%)</td>
<td>13.4 12.6</td>
<td>12.5 12.2 12.1</td>
<td>13.4 12.8 11.8</td>
<td>13.1 12.5 11.9</td>
</tr>
<tr>
<td>Sugar production (t/ha)</td>
<td>21.1 20.5</td>
<td>17.7 17.7 17.7</td>
<td>24.1 24.0 21.7</td>
<td>21.0 20.7 19.7</td>
</tr>
<tr>
<td>Harvest age (months)</td>
<td>13.7 13.7</td>
<td>12.8 12.8 12.8</td>
<td>14.4 14.4 14.4</td>
<td>13.6 13.6 13.6</td>
</tr>
<tr>
<td>TCHM</td>
<td>11.5 11.9</td>
<td>11.1 11.3 11.4</td>
<td>12.5 13.0 12.8</td>
<td>11.7 12.1 12.1</td>
</tr>
<tr>
<td>TAHM</td>
<td>1.54 1.49</td>
<td>1.38 1.38 1.38</td>
<td>1.67 1.66 1.51</td>
<td>1.53 1.51 1.45</td>
</tr>
<tr>
<td>Total water applied (mm)*</td>
<td>319 223</td>
<td>511 382 334</td>
<td>365 329 194</td>
<td>438 356 264</td>
</tr>
</tbody>
</table>

Three inter-furrow distances were evaluated in drip irrigation: (1) double furrow with 2.6 m between pairs and 0.6 m between furrows, (2) double furrow with 2.4 m between pairs and 0.4 m between furrows; and (3) single-furrow check, spaced at 1.75 m. No differences were found in cane and sugar production (Table 3).

Table 3—Production of cane variety CC 85-92 on the Malimbú Sugarcane Plantation, located in the Cauca River Valley, Southwestern Colombia, using three planting systems.

<table>
<thead>
<tr>
<th>Production index</th>
<th>Plant crop</th>
<th>First ratoon</th>
<th>Second ratoon</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Double furrows*</td>
<td>Double furrows**</td>
<td>Single furrow***</td>
<td>Double furrows*</td>
</tr>
<tr>
<td>Cane production (t/ha)</td>
<td>159 160 162</td>
<td>143 145 147</td>
<td>187 183 190</td>
<td>163 163 166</td>
</tr>
<tr>
<td>Sugar yield (%)</td>
<td>12.7 13.2</td>
<td>13.1 12.5 12.4</td>
<td>12.4 13.3 12.1</td>
<td>12.3 12.9 12.5</td>
</tr>
<tr>
<td>Sugar production (t/ha)</td>
<td>20.1 21.1</td>
<td>21.2 18.1 18.1</td>
<td>23.2 24.2 22.9</td>
<td>20.0 21.2 20.8</td>
</tr>
<tr>
<td>Harvest age (months)</td>
<td>13.7 13.7</td>
<td>13.7 12.8 12.8</td>
<td>14.4 14.4 14.4</td>
<td>13.6 13.6 13.6</td>
</tr>
<tr>
<td>TCHM</td>
<td>11.6 11.7</td>
<td>11.8 11.2 11.3</td>
<td>13.0 12.7 13.2</td>
<td>11.9 12.0 12.2</td>
</tr>
<tr>
<td>TAHM</td>
<td>1.5 1.5</td>
<td>1.6 1.3 1.4</td>
<td>1.6 1.7 1.6</td>
<td>1.5 1.6 1.5</td>
</tr>
</tbody>
</table>

*Double furrow with 2.6 m between pairs and 0.6 m between furrows
**Double furrow with 2.4 m between pairs and 0.4 m between furrows
***Single-furrow at 1.75 m
In double-furrow or paired-furrow planting systems, the skids of the lifters broke the drip hoses along several stretches and the wagons caused severe damage to the stools. Taking into account that planting in double furrows reduces the capital costs of lateral hoses by 32%, it would be worthwhile to purchase combine harvesters that adapt to this planting system.

In the second ratoon, differences in tonnes of cane per hectare (TCH) were detected which could be attributable to the frequency x spacing interaction ($\alpha = 5\%$). The highest response in terms of TCH (191 t/ha in variety CC 85-92) was found in the weekly drip irrigation in double furrows with 2.6 m between centres of the pair and 0.6 m between rows.

**Conclusions**

- In the three cuts, drip irrigation as compared with gravity irrigation generated a 43% saving in the amount of water used (2010 m$^3$/ha).
- Averaged over the three cuts (two receiving high precipitation and one low precipitation), the production of drip-irrigated cane variety CC 85-92 was 166 t/ha as compared with gravity-irrigated cane, which produced 157 t/ha, a difference of 9 t/ha (6%). Data will be more conclusive once the results of more dry years are available.
- At least five cuts should be included in the economic evaluation of drip irrigation.
- To adapt drip irrigation to the rainfall regime and the soils of the Cauca River Valley, it should be scheduled based on the criterion of a weekly irrigation to obtain significant water savings (40%) without adversely affecting cane production and sugar yields.
- In drip irrigation, the double-furrow planting system (2.6 m × 0.6 m) is economically favourable because the investment in lateral hoses would be reduced by 32%. Taking into account that the mechanical lifter causes damage to the stools and cuts hoses, it would be worthwhile to purchase a combine harvester that adapts to double-furrow planting because it would facilitate the adoption of drip irrigation.
- The fertilisation applied through drip irrigation (fertigation) represented a saving in terms of machinery and labour which should be evaluated in subsequent experiments to determine the system’s efficiency and fertiliser doses and to quantify the added value of fertigation by dripping.

**REFERENCES**


FREQUENCE D'IRRIGATION GOUTTE A GOUTTE POUR LA CANNE A SUCRE SOUS LES TROPIQUES

Par

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MOTS-CLES: Irrigation Goutte à Goutte, Plan d’Irrigation, Economie d’Eau, Production de Canne à Sucre, Colombie.

Resume

L’irrigation goutte à goutte était initialement conçue pour les endroits désertiques où les sols sablonneux ont une faible capacité de rétention d’eau et où la pluie est limitée. Dans la vallée de la rivière Cauca au sud-ouest de la Colombie, les sols ont une forte capacité de rétention et des irrigations fréquentes produisent un excédent d’humidité et un mauvais développement racinaire qui affectent le développement de la culture. L’application fréquente d’eau dans les sols de la vallée de la rivière Cauca est la cause d’un excédent d’eau dans le sol et d’une très faible utilisation des précipitations naturelles. Cette présente étude a été conduite à la plantation de canne à sucre Malimbú, située dans la partie la plus sèche de la vallée de la rivière Cauca où la pluviométrie annuelle est au dessous de 800 mm et où les sols ont une texture loamy à argileuse. L’effet de la fréquence d’irrigation (journalière, deux fois par semaine et hebdomadaire) a été étudiée dans des parcelles sous irrigation goutte à goutte. Un système d’irrigation gravitaire a été utilisé comme contrôle. Pour trois coupes successives, (une vierge et deux repousses), la production de canne à sucre dans les parcelles irriguées par goutte à goutte était de 160 t/ha avec l’irrigation journalière (application de 483 mm), 165 t/ha irrigué deux fois par semaine (application de 356 mm), et 166 t/ha irrigué chaque semaine (application de 264 mm). Pour l’irrigation gravitaire, la canne a produit 157 t/ha avec une application moyenne de 465 mm. La précipitation annuelle moyenne pendant ces trois coupes a atteint 984 mm. Les résultats indiquent l’importance de prendre avantage de non seulement de la capacité de rétention du sol pour stocker l’eau disponible mais aussi des pluies et de la planification de l’irrigation goutte à goutte hebdomadaire des champs de canne à sucre de la vallée de la rivière Cauca, sans affecter négativement la production de canne.
FRECUENCIA DE RIEGO POR GOTEO DE AÑA DE AZÚCAR EN LOS TRÓPICOS

Por
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PALABRAS CLAVE: Riego por Goteo, Lista de Riego, Agua Almacenamiento, Producción de Caña de Azúcar, Colombia.

Resumen
El sistema de riego por goteo fue desarrollado inicialmente para las zonas desérticas donde los suelos tienen bajas capacidades de retención de humedad (arenosos) y las lluvias son escasas. En el valle del Cauca los suelos son de alta capacidad de retención de humedad y la aplicación de riegos frecuentes resulta en excesos de humedad y en el desarrollo de un sistema radical reducido afectando el desarrollo del cultivo. La aplicación de riegos frecuentes en el trópico resulta en excesos de humedad en el suelo y en poco aprovechamiento de la precipitación natural. La presente investigación se realizó en la hacienda Malimbú, que está ubicada en la zona más seca del valle del río Cauca donde la precipitación anual es inferior a 800 mm y los suelos son de textura franca a arcillosa. Se evaluó el efecto de la frecuencia diaria, 2 veces por semana y una vez por semana en las parcelas regadas por goteo. El sistema de riego por gravedad fue tomado como un testigo de referencia. En tres cortes consecutivos (plantilla y dos socas) la producción de caña de las parcelas regadas por goteo con frecuencia diaria fue de 160 t/ha (lámina de riego 483mm), 165 t/ha para la frecuencia de 2 veces por semana (356 mm) y 166 t/ha para la frecuencia semanal (264 mm). La producción de la caña regada por gravedad fue de 157 t/ha con una lámina promedio aplicada de 465 mm. La precipitación promedio recibida durante los tres cortes alcanzó los 984 mm. Los resultados obtenidos indican la importancia de aprovechar la capacidad de almacenamiento de agua aprovechable de los suelos, la efectividad de la precipitación a partir de programar los riegos para la caña de azúcar en el valle del río Cauca siguiendo una frecuencia de riego semanal sin afectar negativamente la producción.
Norris, C. et al.

SUGARCANE MECHANISATION FOR PROFITABILITY AND SUSTAINABILITY UNDER ENVIRONMENTAL CONSERVATION

By

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KEYWORDS: Sugarcane, Mechanisation, Green Cane Harvesting, Small Growers, Sustainability.

Abstract

The paper summarises the findings compiled from contributions of the committee members and from the proceedings of the International Society of Sugar Cane Technologists (ISSCT) Agricultural Engineering Section Workshop held between 3rd and 5th of March 2009 at The University Centre, Kamphaeng Saen Campus at Nakhon Pathom of the Kaestart University, Thailand. The opening addresses gave an excellent overview of the Thailand Industry, which globally is the second largest exporter of sugar, and has over 80% of its farms of less than 20 ha in size. The industry is in a stage of rapid development, with appropriate mechanisation for small growers being a significant issue. The demand for by-products such as ethanol is a significant catalyst for the growth of the industry. The presentations were grouped under the general headings of Machinery and Mechanisation and Management and Logistics, with a focus on mechanisation associated with smaller operations. The field visits associated with the workshop focused on the very significant development which is occurring in appropriate mechanisation for small and medium size growers, as well as the integration of rotation crops with sugarcane and irrigation systems used. In the workshopping sessions, a wide range of issues were discussed, ranging from Crop Production to the Environment. Miller–Grower ‘Politics’ and Health & Safety issues were also seen as issues which could be addressed, with discussion on the potential of ISSCT sanctioning various training courses. Overall, the most significant issue seen to be facing the industry was logistics and cost of cane transport from the field to the mill. Thailand represented an excellent venue for the workshop, because of its rapid growth and the market driven development of appropriate mechanisation for small growers.

Introduction

The Thailand industry consists of a US$2.1b pa industry with a Sugar Act which provides some regulation, which the industry believes is a constraint on progress and requires reviewing. The area under cane is 0.99 Mha, there are 47 mills, and 170 000 growers. Only 10% of the area is Miller Cum Planter, 80% of the growers are very small with farms of less than 20 ha and only a few farmers have up to 100 ha. Thailand currently grows 72 Mt of sugarcane which is harvested annually and 7.57 Mt of sugar is produced, 2 Mt of which is for local consumption. Thailand is the world’s 2nd largest exporter of sugar (5.7 Mt), mainly to Asia. Only 5% of the crop is mechanically harvested and the labour for crop production is mainly from neighbouring countries. Where water is available, they use surface irrigation and some surface type drip irrigation.
The industry strategy is to increase the area under cane by 30% and increase production from 72 Mt to 95 Mt; however, there are threats from other crops and trade barriers. The growers move in and out of cane depending on the price of other commodities.

The 9th ISSCT Agricultural Engineering Workshop was held from Tuesday 3rd March and Thursday 5th of March 2009.

The pre-workshop tour on the 2nd March focused on the area around the Capital, and visited Ayudhaya, Thailand’s world-famous former capital (from AD 1350 to 1767) and now a World Heritage Site. The tour included the ruins which have survived from this once magnificent city, as well as the ruins of Phra Maha That temple, followed by a short elephant ride around the old ruins to Wat Phra Si Sanphet, the major temple in the old Royal Palace compound. Lunch was enjoyed at a local restaurant by the river, after which Wat Yai Chaimongkol and others were visited before returning to Bangkok. The welcome dinner was a very enjoyable Chao Pra Ya river dinner cruise.

The workshop sessions were held at Kamphaeng Saen Campus of Kaestart University, which is at Nakhon Pathom, approximately 90 km West of Bangkok. The workshop included a very well organised field trip to the University farm where machinery for all facets of the industry were presented in excellent static and operating displays. The second field visit was to Chokpradit Farm, Kanchanaburi, with the final workshop session being held there. The delegates then visited the famous Bridge over the Kwai, where lunch was enjoyed before returning to Bangkok.

**Workshop theme**

The workshop addressed the topic: ‘Sugar cane Mechanisation for Profitability and Sustainability Under Environmental Conservation’ with major subject areas addressed including:

- Tillage and land preparation equipment and strategies in Thailand and other countries.
- Mechanisation of crop husbandry operations for smaller growers
- Comparative performance of irrigation strategies
- Harvesting strategies, ranging from developments in cane knife design to issues relating to cane loaders and also performance and cost of chopper harvesting.
- Transport system scheduling, and broader issues such as the role of sugarcane as an energy crop and the impact of this on harvesting and transport systems.
- Alternative uses for sugarcane by small growers.

A workshop session and a plenary session were also held. The focus of the workshop was on the issues facing the Thai Industry.

**Workshop attendance**

The workshop was attended by 40 delegates from nine countries including 17 from Thailand, 6 from Indonesia, 5 from Mauritius, 3 from each of India and Sudan, 2 from each of Uganda and Japan, 1 from Australia and 1 from South Africa. There were also 23 observers and guests from Thailand.

**Program**

Relevant and interesting issues to many industries were raised in the Machinery and Mechanisation presentation sessions.

There has been significant adoption of the New Farming System with mechanical green cane harvesting in Mauritius; however, they are keen to incorporate the trash blanket into the soil. V. Riviere discussed the success they had by using a shredder type topper on the harvester and then using what they call a Flail disc harrow to incorporate the organic matter. Experiments have shown that, although not statistically significant, there was an increase in yield for the plant and each
ratoon up to the 4th with an accumulated increase of 21 t/ha. Just as significant has been the significant increase in soil organic matter which has been observed. Further work reported from Mauritius covered the work at Belle Vue, where equipment for pulverising rocks is being used with a combination of GPS guidance and permanent beds to make a mechanisation-friendly farming system. B. Vandalall described the success being achieved by an integrated approach and the adoption of the principles of ‘New Farming Systems’.

Mechanisation in Thailand was discussed by T. Indrambarya. It was indicated that more than 80% of farms are less than 20 ha in size. They believe that mechanisation is the way to improve productivity, and machinery has been developed to be used with small conventional tractors (<40 kW) and the two-wheel walk behind type tractor. 90% of the cane is harvested manually. Depending on the area, up to 100% of the cane may be harvested as green cane. Many of the practices being developed may be relevant in countries other than Thailand.

The presentation by R. Karoonboonyanan on the development of a vibratory type Subsoiler focused on the issue of undertaking relatively heavy land preparation operations with ‘lighter’ tractors. While there was no advantage in terms of work rate or fuel consumption, the advantage of the vibratory action was that a tractor of a given weight could pull either a wider machine or a narrow machine deeper than would normally be possible, given the tractor weight.

The cane knives in Thailand have traditionally been of a short and straight design. This makes it difficult to cut the stalk close to the ground, as well as having health and safety issues. Work was thus carried out to improve the effectiveness of the knives used to manually cut cane. N. Sokudlor reported on nine different designs which were tested, and a new design known as ‘Phuvieng 4’ was found to be the most effective.

The data from field trials indicated that 41 percent of workers were satisfied with Phuvieng 4 because less cane was left in the field. Cane stalk height after harvesting was reduced from 9.5 cm to 2 cm in height and the benefit was an additional 2 t/ha, resulting in an added income of US$46/ha. This indicates that it may be possible to design an even more ergonomically acceptable knife that enables a higher productivity.

In Thailand, juice is squeezed from cane stalks to provide fresh drinking juice, which provides some small growers a higher value for their cane; however, to make the taste acceptable, the rind is removed to remove the wax. The peeling process to achieve this is labour intensive and slow. A system described by P. Pruengam was developed to grind away the outer surface of the rind before the juice was squeezed out. The simple electrically driven grinder increased a labourer’s productivity by a factor of four and 20% less juice was lost than in the peeling process.

C. Norris gave a presentation entitled ‘Sugar cane; Reconsidering Harvesting Strategies for Cost-Effective Energy Recovery’. The traditional use of sugarcane captures less than half of the recoverable energy of the crop, often with less than optimal environmental stewardship.

The increased energy costs of recent times caused many paradigms to change in sugar industries around the globe, with sugarcane trash being considered as a viable replacement for fossil fuels in many applications. He discussed an analysis of a number of different sugarcane trash recovery strategies, investigating the costs associated with each, as well as a broad range of issues including agronomic cost or benefit, the quality of the fuel delivered, and the technology requirement and availability. He argued that, while systems where trash is delivered with the cane and separated at the mill are likely to be the most viable strategy into the future, further technology development is required.

P. Lyne presented their work relating to scheduling of vehicles for the road transport of sugarcane. The paper illustrated the very significant gains which can be made with respect to total investment and cost of sugarcane transport to the mill. This work has significant relevance in a wide range of industries.
Poster session

A. Boontham showed a mechanical system that was used to detrash cane prior to manual harvesting. The cane trash extractor consisted of two cages with cable strings attached to each cage for removing the old leaves. The cane detrasher is attached to a two-wheel walk behind tractor.

There was also a concern in Thailand about fires with cane trash on the surface. There is now considerable emphasis on the development of systems to incorporate the trash after harvest. Trash incorporators can be based on a range of machines including disc harrows with notched blade discs, rotavators or disc ploughs. This technology will undoubtedly increase in relevance for other countries as they move towards green cane harvesting.

N. Sokudlor presented work on the development of various tools to be used for detrashing in place of using the knives to remove trash. The cutters could change activities during the day and there was less injury due to the continuous conventional method of cutting and trash cane. Leaf trash in the delivered product reduced from 6.9 to 2.9 percent. The equipment was also tested in farmers’ fields. About 95 percent of cutters were satisfied with the equipment because it eased their workload; however, the remainder still complained of additional work. With the detrashing tool, cutters increased daily productivity by 20 – 25 bundles/day (each bundle is 10 sticks of cane) resulting in an additional income. The operation of pre-stripping can be carried out up to 2 weeks prior to harvesting.

Y. Tarumoto from Japan described a Regional Simulation Approach for Evaluating New Sugarcane Varieties Using System Dynamics. Because the sugar industry is a very complex system, it is difficult to quantify or predict the outcome of changes. Different traits in different varieties is one example. Therefore, a System Dynamics simulation model was developed using the software Vensim to examine consequences. The steps involved included simulation of the weekly changes in sucrose for different crops, and the development of appropriate harvest quotas to maximise sucrose production and minimise industry costs. The model shows not only an industry wide effect but also detailed analysis on a field by field basis. This is useful to assist the discussion between stakeholders on issues such as crush dates or adoption of new varieties.

Chopper harvesters are used for approximately 5% of the Thailand crop, with about 250 harvesters involved. S. Khawprateep carried out a study involving 30 machines, differentiated into one of two groups by engine power, i.e., high power models with typical engine power of 240 kW, and lower power models fitted with engines of approximately 177 kW. The study was conducted over a period of 5 years, and determined productivity and fuel consumption of the different machines.

The result showed that the average sugarcane cut was 9769 tonnes/year and the average rate of fuel consumption was 2.60 litres/tonne. Analysis of the work capacity and fuel consumption between two engine sizes showed an average productivity of 8219 and 11 319 tonnes/year with the average fuel consumption at 2.53 and 2.68 litres/tonne, respectively for the low power and high power units.

Even given the average season length of 13 weeks for machine harvesting, this is considered to be a very low productivity, with small fields considered a major factor. The authors noted the target for Australian operators over this period would be 50 000 tonnes and a fuel consumption of 1 litre/tonne.

Field visits

The field demonstration at the university farm included an impressive array of machinery, ranging from tractor-drawn equipment for larger growers and contractors to equipment based on small tractors and also equipment fitted to walk-behind tractors. Each display was well organised and the accompanying posters gave very useful information.
The coverage of different systems was comprehensive yet in very useful detail. Considerable time had obviously been spent ensuring appropriate conditions were in place for each of the very wide range of machines to be demonstrated to their maximum advantage.

The field visit to Chokpradit Farm, Kanchanaburi allowed delegates to see the planting and post-planting irrigation being undertaken on a larger farm, which was also of significant interest.

Acknowledgements

The Agricultural Engineering Section Committee thanks all formal delegates and observers who participated in the Workshop, with special thanks to those who prepared and presented papers.

The committee gratefully acknowledges the enormous time input by Mr Borpit Tangwongkit and his team at the Farm Mechanisation section of the Kasetsart University, for organisation of the workshop.

The committee also acknowledges the very generous support of the major and minor sponsors of the Workshop. The Council of the ISSCT is thanked for entrusting the Agricultural Engineering Section Committee with the task of organising the Workshop and for providing necessary support.

MECANISATION POUR UNE PRODUCTION DE CANNE À SUCRE PROFITABLE ET DURABLE DANS LA CONSERVATION DE L’ENVIRONNEMENT

Par

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MOTS CLES: Canne à Sucre, Mécanisation, Récolte en Vert, Petits Producteurs, Agriculture Durable.

Résumé

Le papier résume les conclusions compilées à partir des contributions des membres du comité et du rapport du workshop de la Section de Mécanisation Agricole de l’ISSCT tenu entre les 3 et 5 mars 2009 au Centre Universitaire, Campus de Kamphaeng Saen à at Nakhon Pathom de l’Université de Kaestar, Thaïlande. Les discours d’ouverture donnèrent un excellent survol de l’Industrie thaïlandaise, qui au niveau global est le deuxième plus grand exportateur de sucre, avec 80% des unités de production d’une taille inférieure à 20 ha. L’industrie est à un stade de développement rapide, avec la mécanisation appropriée pour les petits producteurs comme problématique importante. La demande pour les sous-produits, tel l’éthanol est un catalyseur significatif pour la croissance de l’industrie. Les présentations étaient regroupées sous des rubriques générales de Machines et Mécanisation et Gestion et Logistiques, avec une emphase sur la mécanisation associée aux plus petites opérations. Les visites aux champs, associées au workshop, se sont concentrées sur le développement significatif de la mécanisation qui est actuellement en cours pour les petits producteurs et ceux de taille moyenne, aussi bien que sur l’intégration des cultures en rotation avec la canne à sucre et les systèmes d’irrigation utilisés. Dans les sessions de discussion, une large gamme de sujets variant entre la production agricole et l’environnement, ont été débattus. Les ‘politiques’ des usiniers-planteurs et les questions sur la santé et sécurité ont été considérées comme
MECANIZACIÓN DE LA CAÑA DE AZÚCAR PARA RENTABILIDAD Y SOSTENIBILIDAD BAJO EL ESQUEMA DE CONSERVACION AMBIENTAL

Por

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PALABRAS CLAVE: Caña de Azúcar, Mecanización, Cosecha de Caña Verde, Pequeños Productores, Sostenibilidad.

Resumen

EL DOCUMENTO resume los resultados compilados de las contribuciones de los miembros del comité y las memorias del Seminario de la Sociedad Internacional de Tecnólogos de la Caña de Azúcar (ISSCT) Sección de Ingeniería Agrícola, celebrado entre el 3 y 5 de marzo 2009 en el Centro Universitario, Kamphaeng Saen Campus en Nakhon Pathom, de la Universidad Kaestart, Tailandia.

Los discursos de apertura dieron un excelente panorama de la Industria de Tailandia, que a nivel mundial es el segundo mayor exportador de azúcar, y tiene más del 80% de las explotaciones de un tamaño menor de 20 ha. La industria está en una etapa de rápido desarrollo, pero un problema importante es la falta de mecanización apropiada para los pequeños productores. La demanda de productos derivados como el etanol es un catalizador importante del crecimiento de la industria. Las presentaciones fueron agrupadas bajo los encabezados generales de Maquinaria y Mecanización, y Manejo y Logística, con especial atención a la mecanización asociada con la operación en pequeña escala. Las visitas de campo relacionadas con el taller se enfocaron en el muy importante desarrollo que está ocurriendo en la mecanización apropiada para pequeños y medianos productores, así como en la integración de cultivos de rotación con caña de azúcar y los sistemas de riego utilizados.

En las sesiones de taller, fue discutida una amplia gama de temas, cubriendo desde producción agrícola hasta consideraciones ambientales. Otros puntos que se consideró podrían ser tratados fueron, la ‘Política’ de Miller para los cultivadores, y problemas de Salud y Seguridad. También se debatió sobre el potencial de ISSCT para implementar diversos cursos de capacitación. En general, se identificaron la logística y el costo de transporte de la caña desde el campo hasta la fábrica como los problemas más importantes que está enfrentando la industria. Tailandia fue un lugar excelente para el taller, debido a su crecimiento rápido y al desarrollo del mercado de la mecanización apropiada para cultivadores pequeños.
MONITORING SUGARCANE CROPS IN THE CAUCA RIVER VALLEY (COLOMBIA), USING MODIS SATELLITE IMAGES

By

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KEYWORDS: Sugarcane, Yield Forecasting, MODIS, Enhanced Vegetation Index, Time Series.

Abstract
MODIS product MOD13Q1 was used to monitor the sugarcane crop, using an enhanced vegetation index in the Cauca River Valley for a time series from 2000–2006. The product consists of images taken every 16 days (pixel size of 250X250 m), which makes it possible to work with fields larger than 6.25 ha. A methodology was developed for downloading, cutting, filtering and laying out the time series of the vegetation indices on Internet for the entire area planted with sugarcane. The relation between the time series and the information on crop establishment and harvesting of the fields indicated that the satellite data were consistent with the phenology of the sugarcane crop. Similarly, there was a high correlation between the cumulative vegetation index and cane production. Low index values were associated with low values of tonnes of cane per hectare; whereas high index values meant high production values.

Introduction
A practical and unique way of monitoring large extensions of agricultural zones is by means of remote perception. Studies done on different crops show that the MODIS (MODerate Resolution Imaging Spectroradiometer) 250-m data are correlated with productivity (Doraiswamy et al., 2005; Bastidas-Obando and Carbonell, 2006; Colditz et al., 2006; Wardlow et al. 2007). The purpose of this work was to evaluate the consistency of the MOD13Q1 product and generate a model for forecasting productivity in terms of tonnes of cane per hectare (TCH) for the sugarcane crop in the Cauca River Valley (CRV).

Methodology

Study area
The study area, which covers 212 000 ha, is located in the CRV of Colombia, between 3° and 5° latitude N and 76°22’ and 75°31’ longitude W.

Processing the MOD13Q1 product
For monitoring the cane crop in the CRV, the product ‘MODIS/TERRA VEGETATION INDICES 16-DAY L3 Global 250 m SIN GRID V004’ was used. The images were cut in the study area and projected to a Transverse Mercator using the MODIS Reprojection Tools.

The time series from February 2000 to December 2006 (360 × 931 pixels) was generated using the enhanced vegetation index (EVI). The EVI time series was interpolated from QA-SDS quality data, followed by the Savitzky-Golay smoothing filter method (Chen et al., 2004).

Statistical analyses
For the analyses, a total of 6857 pixels were selected, corresponding to an area of 43 481 ha. A regression analysis was conducted to relate the information from MODIS with the production
data, for which the area under the curve of each crop cycle was accumulated and compared with its respective TCH.

**MapServer**

A Web application was developed to compare the time series with the full information from the commercial database. This application is available for the entire area planted with sugarcane in the CRV and is updated every 16 days.

**Results and discussion**

Figure 1 shows how using the QA-SDS quality parameters and the Savitzky-Golay filter method made it possible to obtain high-quality time series information (Chen et al., 2004).

![Figure 1](image)

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A total of 48 cumulative EVI ranges were determined, and the existing TCH data for each range were averaged. These data were used in a regression analysis, weighted for the number of data for each interval, as follows:

\[ e = 0.0005x + 53.139 \]  
(where: \( e = \text{TCH} \); \( x = \text{Cumulative EVI} \))

with a regression coefficient of determination \( r^2 = 0.83 \), which is a high value given that the ranges cover the entire variation due to variety, agro-ecological zones, agronomic practices and age at cut.
With the recorded data, cumulative EVI ranges were formed with respect to what one lot of sugarcane should have at a given crop age (in months) in order to reach a TCH value with a 95% confidence level (Table 1). This makes it possible to evaluate whether there is an anomaly in the development of the crop, thereby facilitating an early warning about its current condition.

Table 1—Monthly cumulative EVI values and their relation to final production.

<table>
<thead>
<tr>
<th>Crop age (months)</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of observations</td>
<td>2019</td>
<td>2196</td>
<td>2396</td>
<td>2380</td>
<td>2391</td>
</tr>
<tr>
<td>SD TCH</td>
<td>25.43</td>
<td>26.31</td>
<td>25.12</td>
<td>24.66</td>
<td>23.95</td>
</tr>
<tr>
<td>Average TCH</td>
<td>125.23</td>
<td>121.69</td>
<td>124.29</td>
<td>125.44</td>
<td>126.72</td>
</tr>
<tr>
<td>TCH limit (Low–High)</td>
<td>124.12–126.33</td>
<td>120.58–122.78</td>
<td>123.28–125.29</td>
<td>124.45–126.43</td>
<td>125.76–127.68</td>
</tr>
<tr>
<td>Error (95% confidence level)</td>
<td>1.1</td>
<td>1</td>
<td>1</td>
<td>0.99</td>
<td>0.96</td>
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</table>

Conclusions

The use of the quality data and the application of the Savitzky-Golay filter (Chen et al., 2004) improve the original MOD13Q1 time series. The information is consistent with the development of the cane crop and its productivity. Discounting the intercept, the model $TCH = 0.0005 \text{EVI} + 53.139$ revealed that, for every 10 000 cumulative EVI units, there is an increase of 5 TCH.

The effect of agronomic practices such as the application of fertilisers, herbicides, maturants and irrigation on the crop’s spectral response needs to be evaluated. Similarly, there is a need to identify patterns or cumulative values early enough in order to develop an expert system based on the MODIS data.

REFERENCES


UTILISATION DES IMAGES SATELITE MODIS POUR LE SUIVI DE LA PRODUCTION DE CANNE DANS LA VALLEE DE LA RIVIERE CAUCA (COLOMBIE)

Par

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MOTS-CLES: Canne à Sucre, Prévision du Rendement, MODIS, Indice de Végétation Amélioré, Série Temporelle.

Résumé

Le produit MOD13Q1 de MODIS a été utilisé pour suivre la production de la canne à sucre avec un indice de végétation amélioré dans la vallée de la rivière Cauca pour la série temporelle 2000-2006. Le produit comprend des images (taille de pixel 250 × 250m) pris chaque 16 jours, ce qui permet de travailler avec des champs d’une superficie supérieure à 6.25 ha. Une méthodologie pour télécharger, couper, filtrer et étendre la série temporelle des indices de végétation sur Internet a été développée pour toute la zone plantée de canne à sucre. La relation entre la série temporelle et les informations sur l’établissement de la culture et la récolte des champs a indiqué que les données satellite étaient consistantes avec la phénologie de culture de canne à sucre. Il y avait aussi une forte corrélation entre l’indice cumulatif de végétation et la production de canne. Des faibles valeurs d’indices étaient associées avec des faibles tonnages de canne à l’hectare alors que des valeurs fortes indiquaient des fortes productions.
MONITOREO DEL CULTIVO DE LA CAÑA DE AZUCAR EN EL VALLE DEL CAUCA (COLOMBIA) USANDO IMAGENES SATELITALES MODIS

Por

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PALABRAS CLAVE: Caña de Azúcar, Predicción del Rendimiento, MODIS, Índice de Vegetación Mejorado, Series de Tiempo.

Resumen
El producto MOD13Q1 de MODIS, fue usado para realizar un seguimiento del cultivo de la caña de azúcar en el valle del río Cauca para la serie de tiempo comprendida entre 2000 y 2006 usando un índice de vegetación. El producto consta de imágenes compuestas cada 16 días con un tamaño de pixel de 250 × 250 m, lo que permite trabajar con campos mayores a 6.25 ha. Fue desarrollada una metodología para la descarga, corte, filtrado y disposición de las series de tiempo de los índices de vegetación en Internet para toda el área sembrada con caña de azúcar. La relación entre las series de tiempo con la información de establecimiento y cosecha de los campos indica que los datos satelitales son consistentes con la fenología o desarrollo vegetal del cultivo de la caña de azúcar. A su vez se evidencia una alta correlación entre el índice de vegetación acumulado y la producción de caña. Valores bajos de índice están asociados con bajos tonelajes de caña por hectárea (TCH), y por el contrario, altos valores del índice significan altos valores de TCH.
IRRIGATING SUGARCANE WITH VERY LOW FURROW INFLOW RATES

By

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KEYWORDS: Furrow Irrigation, Sugarcane, Low Inflow, Low Cost.

Abstract

SPRINKLER irrigation of sugarcane is a common practice at the foothills of the Cauca river valley of Colombia. Energy costs are limiting the use of this irrigation system and alternative ways of irrigation using small surface springs is under evaluation. Water is applied by gravity using small furrow inflow rates in the range of 0.1 to 0.3 L/s while furrow irrigation of sugarcane on the flat areas uses inflow rates above 5 L/s. Water is diverted from the small streams and conducted to the fields using small hydraulics heads (less than 10 m). Cheap pipelines of 100 mm diameter, made of recycled polyethylene bags, are used to conduct the water at low pressure heads to the fields where water is applied to the furrows using plastic tubing of 6 to 16 mm in diameter. Furrow lengths of 100 to 120 m with slopes above 1% are irrigated during the advance phase in 20 to 24 hours applying water depths in the range of 100 to 130 mm. Cane yields in the order of 84 t/ha were obtained, which compare very well with the production of the sprinkle-irrigated plots.

Introduction

In the Cauca river valley of Colombia, there are 205 664 ha of cane planted. Of this area, 62 636 ha are in the foothills of the central and oriental mountain chains. The cropped area is characterised by the presence of shallow depth soils, and high gravel content (20 to 50%); therefore, water holding capacity and fertility levels are low. During dry spells, it is necessary to sprinkle irrigate the cane fields, which results in high energy inputs, high water consumption and high soil erosion risk due to terrain slopes above 1%.

Bohorquez and García (1985) in Venezuela applied very low furrow inflow rates to improve irrigation efficiencies in an area with low surface water availability. Díaz and Prieto (2000) evaluated the application of low inflow rates (0.1 L/s) to irrigate sugarcane in a soil with low infiltration capacity, slow internal drainage and slopes between 2–3%. They were able to increase water storage and use efficiency. As a way to adapt to the climate change in years with the presence of the El Niño phenomenon, Cenicaña has been evaluating the practicality of using surface irrigation with very small furrow inflow rates to irrigate sugarcane.

Methodology

This system, referred to as furrow irrigation with low inflow rates, uses water diverted from small streams. Typically, low hydraulic heads (less than 10 m) are available to convey the water to the fields. Cheap pipelines of 100 mm diameter, made of recycled polyethylene bags, are used to conduct the water at the low pressure heads to the fields. Water is applied to each furrow using plastic tubes of 6 to 16 mm in diameter. Water is applied by gravity using small furrow inflow rates in the range of 0.1 to 0.3 L/s. The conventional furrow irrigation practice of sugarcane on the flat areas uses inflow rates above 5 L/s. With the new system, furrow lengths of 100 to 120 m are typical, with slopes above 1%. The irrigation water advance phase is 20 to 24 hours, applying water
depths in the range of 100 to 130 mm. Water applied to the furrow inlets creates a kind of ponded zone in a distance of 2 to 3 m, and then it advances through the soil as horizontal infiltration and, after 20 to 24 hours of continual water supply, it reaches the end of the cane row. The slow application of water, using furrow inflow in the range of 0.1 to 0.3 L/s, results in a pronounced lateral movement of the water front. The water advance along the furrow length is controlled by gravity and by the presence of a coarser soil layer underneath the surface soil layer, which acts as a barrier to vertical water flow due to the high discontinuity in hydraulic conductivity between the surface and the underlying soil.

The system has been under evaluation at the foot hills of the Central mountain range in a farm (Vallecito) of Castilla sugar estate. The soil is considered as a Mollisol with skeletal clay textural family, and the field slope varies between 1.7 and 4.9%. The experiment followed a randomised complete block design with six water inflow rates (0.00, 0.06, 0.08, 0.10, 0.11 and 0.12 L/s) as treatments and four replications were established. The nearby field sprinkler irrigated and managed by the sugar estate was taken as a reference. The test cane variety was Co 421 planted by the sugar estate in this area.

Results and discussion

The hydraulic system to convey and deliver water to the cane was installed at the beginning of the fourth ratoon which was harvested at 11.5 months of age (Table 1). During the crop cycle, precipitation amounted to 1025 mm, and 1856 mm of evaporation occurred. Irrigation was applied according to Cenicaña’s water balance calculations. On average, five irrigation events were applied to the experimental area under reduced inflow rate application. The irrigation water depth varied between 205 and 956 mm. As a result of the non uniform slope of the furrows, in places where the furrow slope was higher, the water advanced faster, resulting in the applied water depth being smaller. The total amount of water received by the crop ranged from 1063 mm for the plots without irrigation up to 1981 mm for the treatment with inflow rates of 0.07 L/s. Cane yields within the plots irrigated with reduced inflow rates varied between 56 to 80 t/ha as compared with the sprinkler-irrigated field that yielded 56 t/ha with an applied irrigation depth of 70 mm for two irrigation events. It is necessary to recognise that, under the experimental area, there was high variability due to soil conditions and field slope that induced unexpected changes in water advance times, water advance velocity and total irrigation water depths.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Flow rate (L/s)</th>
<th>Irrigation water depth (mm)</th>
<th>Total water received (mm)</th>
<th>TCH</th>
<th>Sucrose % cane</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1063</td>
<td>56c</td>
<td>12.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.07</td>
<td>812</td>
<td>1837</td>
<td>56c</td>
<td>10.9</td>
</tr>
<tr>
<td>2</td>
<td>0.08</td>
<td>956</td>
<td>1981</td>
<td>75ab</td>
<td>10.6</td>
</tr>
<tr>
<td>3</td>
<td>0.11</td>
<td>602</td>
<td>1627</td>
<td>61bc</td>
<td>10.7</td>
</tr>
<tr>
<td>4</td>
<td>0.11</td>
<td>258</td>
<td>1283</td>
<td>80a</td>
<td>10.7</td>
</tr>
<tr>
<td>5</td>
<td>0.12</td>
<td>205</td>
<td>1230</td>
<td>59cb</td>
<td>11</td>
</tr>
<tr>
<td>Mean</td>
<td>64</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV%</td>
<td>17</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signific, %</td>
<td>2</td>
<td>NS</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Conclusions

The results from this evaluation are very promising, and it can be concluded that the reduced inflow rate system of irrigation could be adjusted to match the local conditions of individual fields. It is expected to improve cane yield of commercial fields by adjusting water application rates and the fertiliser rates according to the content of gravel in the soil and the available soil water holding capacity. The system opens the possibility to use depleted surface water streams and use low cost
plastic pipes which make it attractive to be used in rural area to irrigate cash crops. The system has been under evaluation by Cenicaña in different parts of the foot hills of the Cauca river valley.

REFERENCES


L’IRRIGATION DE LA CANNE A SUCRE A TRES FAIBLE DEBIT DE RAIE

Par

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MOTS CLES: Irrigation à la Raie, Canne à Sucre, Faible Débit, Coût Faible.

Résumé

L’IRRIGATION de la canne à sucre par aspersion est une pratique courante au pied des collines de la vallée de la rivière Cauca de Colombie. Les coûts énergétiques limitent l’utilisation de ce système d’irrigation et d’autres moyens d’irrigation utilisant des petites sources de surface sont en cours d’évaluation. L’eau est appliquée par gravité avec des faibles débits de raie entre 0.1 et 0.3 L/s alors que l’irrigation à la raie sur des surfaces plates utilise des débits supérieurs à 5 L/s. L’eau est déviée des petits ruisseaux et conduite aux champs avec des faibles charges hydrauliques (moins de 10 m). Des raccords bon marché de 100 mm de diamètre, fabriqués avec des sacs de polyéthylène recyclé, sont utilisés pour conduire l’eau à basse pression aux champs où elle est appliquée aux sillons avec des tubes en plastic de 6 à 16 mm de diamètre. Les sillons de 100 à 120 m de long avec des pentes supérieures à 1% sont irrigués pendant la phase d’avancement en 20 à 24 heures appliquant des profondeurs d’eau dans la gamme de 100 à 130 mm. Des rendements canne de l’ordre de 84 t/ha, qui se comparent très bien à ceux des parcelles irriguées par aspersion ont été obtenus.
RIEGO DE LA CAÑA DE AZUCAR CON MUY BAJOS CAUDALES POR SURCO

Por

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PALABRAS CLAVE: Irrigación por Gravedad, Caña de Azúcar, Bajo Caudal, Bajo Costo.

Resumen

El riego de la caña de azúcar por aspersión en los piedemontes del valle del río Cauca en Colombia. Los costos de la energía limitan el uso de este sistema y se están ensayando formas alternativas de riego usando pequeñas corrientes superficiales. El agua se aplica por gravedad usando pequeños caudales por surco entre 0.1 y 0.3 L/s mientras en el riego por surcos de la caña en las zonas planas se usan caudales por surco mayores a 5 L/s. El agua se deriva de pequeñas corrientes y se conduce a los campos usando pequeñas cabezales hidráulicas (menores de 10 m). Tuberías de bajo costo de 100 mm de diámetro, hechas de polietileno reciclado, se utilizan para conducir el agua a baja presión a los campos donde el agua es aplicada a los surcos usando tubos plásticos de 6 a 16 mm de diámetro. Longitudes de surco de 100 a 120 m con pendientes mayores del 1% se riegan en tiempos de avance de 20 a 24 horas aplicando láminas entre 100 y 120 mm. Se obtuvieron productividades de caña del orden de 84 t/ha, que compiten muy bien con la producción de las parcelas regadas por aspersión.
CHANGE OF SUGARCANE PRODUCTION AFTER INTRODUCTION OF DE-TRASHING EQUIPMENT: A CASE STUDY OF IZENA ISLAND

By

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Abstract

This paper will discuss the relationships between an ageing population of sugarcane growers on Izena Island, the introduction of mechanical de-trashing procedures, subsequent changes in soil management practices and the implications for continuing productivity. The farming demographic in Okinawa Prefecture, and Izena Island in particular, between 1995 and the present day reveals a decrease in sugarcane production, an average farm size at 1 hectare or less, and the average age of the farmer at 65 years or more. Statistics reveal also that the succession of farm land and farming, as an occupation from one generation to the next, is not an enduring tradition. With their increasing age, sugarcane growers have been more accepting of mechanical procedures that ease the physical burden of their workload but, as this paper reveals, such procedures can sometimes have unexpected consequences. Prior to mechanical intervention, the dead leaves (trash) were removed from the cane stalks before transportation to the mill, and therefore remained on the farm where they were subsequently returned to the soil as organic matter. With the new de-trashing procedures, the trash is removed with the cane stalks to the mill, where it is composted as a by-product of the milling process. Furthermore, where previously each farm retained its own trash for composting, the mechanical processing at the mill has resulted in uneven distribution and supply of composted trash to farmers. This has raised concerns about deteriorating soil fertility, decreasing productivity and inadequate water conservation due to lack of organic material in the soil.

Introduction

Okinawa Prefecture is sub-tropical and consists of large and small islands. Izena Island is a solitary island in the northern part of Okinawa Prefecture. Sugarcane is the main industry on each island and in the economy of Okinawa Prefecture. However, the production of sugarcane in Okinawa Prefecture is decreasing, and the age of growers is on the increase.

According to previous research, there is a causal relationship between the low quantity of production and an accumulation of inadequate cultivation techniques (Fukunaka et al., 1999; Kikuchi, 2005). Moreover, implementation of fertilisation management influences the quantity of production (Kikuchi et al., 2007). Izena Island introduced de-trashing equipment early in Okinawa Prefecture. While the growers’ age was increasing, introduction of de-trashing equipment which can reduce harvest work had a big influence. However, fertilisation management suffered and production decreased. After introducing de-trashing equipment, growers ceased the return of trash to the farm at harvest, which reduced organic matter in the soil and may be responsible for reduced production. The purpose of this paper is to examine how to maintain soil fertility.
Research methods

Investigation was conducted over two years (2004 and 2008), in order to clarify a possible relationship between the use of de-trashing equipment and production trends. In November 2004, 42 households contributed data for the study. Information gathered on each household included the grower’s age, the existence (or not) of a successor to the current grower, the types of sugarcane grown, as well as details on the use of irrigation, deep ploughing, and moulding. In August 2008, 26 of the households were re-surveyed.

Results and discussion

The rate of trash, and its relation to unit crop yield

The harvested area in Okinawa Prefecture decreased to 12,485 ha in 2004 (Figure 1). Yield of cane peaked at 84.8 t/ha in 1990 and has now decreased to 60–70 t/ha.

If an ageing grower does not have a successor, the farmland may be abandoned. However, de-trashing equipment has reduced labour on the farm, so older farmers have continued to farm.

Before 1993, the leaf was peeled off before harvest, and the dead leaf was returned to the farmland. Per unit crop production was around 60 t/ha. However, after 1997, per unit crop production could not maintain 60 t/ha (Figure 2).

After 1993, when de-trashing equipment was introduced, the amount of trash for each 1 ha shows the tendency to increase because it omits the peeling off of the leaf by the grower. Before 1993, an average of 1.5 t/ha of trash was left on the field after harvest.

However, after 1994 when de-trashing equipment was introduced, an average of 6.2 t/ha of trash is returned to farmland but only to specific growers. Average fertility of soil has decreased, and production has decreased.
In Izena village, the de-trashing system is as follows. Cane is cut at the base and the cane top is removed. Cane and tops are picked up by a crane (Figure 3) and transported to the de-trashing equipment. Trash is removed in the de-trashing equipment and is processed in the sugarcane mill. Trash is taken to the compost factory, and is composted. In Izena village, the actual quantity of compost produced is from 3000 to 3500 t/year. The compost is only returned to 23.4% of the farmland.
Soil fertility must be maintained to maintain production. The compost is indispensable in maintenance of soil fertility. However, in Izena, there is a problem in the source of supply being restricted. Compared with the number of growers, the source of supply of organic matter in the village is restricted. Compost can be supplied to only about 40% of growers. Livestock faeces and urine discharged from dairy cattle in the village are processed in the compost factory. However, because there are few animals in the village, the absolute quantity of organic matter is insufficient.

All stems carried to the mill by truck are fed into the sugar mill through the cane feeder, and proceeds through the sugar mill as indicated by the red arrows (Figure 4). The first stage of trash separation is wind-powered, and the soil and sand is filtered out in the rotational separator. After passing through 3 wind-powered separators, the de-trashed raw material passes onto the clean cane conveyor and is carried into the sugar mill. The wind velocity used in the de-trashing equipment varies according to mill, and it can be adjusted in each de-trashing according to the raw materials.

*Fig. 4—De-trashing equipment. Produced by Tsukishima Co. Ltd.*

**Amount of fertiliser applied and unit crop**

Growers investigated were 42 households (2004) and 26 households (2008). This paper classified the grower by using the same index for two years (Tables 1 and 2). The full-time growers of sugarcane are farm manager husband and wife. Harvest area is 1 ha or more.

<table>
<thead>
<tr>
<th>Table 1—Management form standard (2004).</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Corresponding grower.</strong></td>
</tr>
<tr>
<td>Full-time grower of the sugar cane</td>
</tr>
<tr>
<td>Aged full-time grower</td>
</tr>
<tr>
<td>Part-time grower</td>
</tr>
<tr>
<td>Petty grower</td>
</tr>
</tbody>
</table>

*Source: From the investigation.*
Table 2—Management form standard (2008).

<table>
<thead>
<tr>
<th></th>
<th>Corresponding grower</th>
<th>Grower who engages in own agriculture</th>
<th>Number of growers engaged in own farming</th>
<th>Harvest area (ha)</th>
<th>Average unit crop (t/ha)</th>
<th>Grower age</th>
<th>The rate of successor reservation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full-time cane grower</td>
<td>4</td>
<td>Mainly farm operator husband-and-wife</td>
<td>2 or more</td>
<td>1 ha or more</td>
<td>93.8</td>
<td>Less than 60</td>
<td>50.0</td>
</tr>
<tr>
<td>Aged full-time grower</td>
<td>11</td>
<td>Mainly farm operator husband-and-wife</td>
<td>2 or more</td>
<td>–</td>
<td>53.6</td>
<td>65 or more</td>
<td>18.2</td>
</tr>
<tr>
<td>Part-time grower</td>
<td>8</td>
<td>Only grower</td>
<td>One person.</td>
<td>1 ha or more</td>
<td>57.5</td>
<td>40~64</td>
<td>50.0</td>
</tr>
<tr>
<td>Petty grower</td>
<td>3</td>
<td>Only grower</td>
<td>–</td>
<td>0.9 ha or less</td>
<td>54.2</td>
<td>–</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Source: From the investigation.

The age of the full-time farm manager is 60 years or less, and it is a grower who has a successor. The aged full-time grower was classified according to agricultural continuity and an age element. Those who are engaged in agriculture aged 65 and over cannot start work in other industries. It is a grower who is making agriculture a principal occupation.

A part-time farm grower is only a farm manager. Only 30–50% of these growers have a successor, and do not work full-time on the farm. The manager’s wife works in other industries and is not engaged in agriculture at all, which reduces the labour force. In addition to agricultural income, the livelihood of the grower is realised by income other than agriculture. A petty grower has a harvested area of 0.9 ha or less, and is engaged in agriculture only as a manager. The manager is also working in other industries. Agricultural income is only a part of gross income.

The full-time grower of the sugarcane should use 30–45 t/ha of organic fertiliser. However, the actual amounts of fertiliser are insufficient (Tables 3 and 4). The grower is compensating this insufficiency with chemical fertiliser. With commercial fertiliser, 500 kg/ha is required, but seems excessive. To increase crop yields, growers used a lot of commercial fertilisers.

Table 3—The actual situation of the main fertilisation management (2004).

<table>
<thead>
<tr>
<th></th>
<th>Unit crop(t/ha)</th>
<th>Enforcement rate of molding (%)</th>
<th>Enforcement rate of irrigation (%)</th>
<th>Rate of use of chemical fertiliser (t/ha)</th>
<th>Rate of use of organic fertiliser (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full-time sugar grower</td>
<td>58.9</td>
<td>100.0</td>
<td>60.0</td>
<td>1.7</td>
<td>35.2</td>
</tr>
<tr>
<td>Aged full-time grower</td>
<td>47.3</td>
<td>88.9</td>
<td>38.9</td>
<td>2.1</td>
<td>45.2</td>
</tr>
<tr>
<td>Part-time grower</td>
<td>55.6</td>
<td>88.5</td>
<td>61.5</td>
<td>2.1</td>
<td>34.0</td>
</tr>
<tr>
<td>Petty grower</td>
<td>43.5</td>
<td>100.0</td>
<td>50.0</td>
<td>1.8</td>
<td>23.7</td>
</tr>
</tbody>
</table>

Source: From the investigation.

Table 4—The actual situation of the main fertilisation management (2008).

<table>
<thead>
<tr>
<th></th>
<th>Unit crop(t/ha)</th>
<th>Enforcement rate of molding (%)</th>
<th>Enforcement rate of irrigation (%)</th>
<th>Rate of use of chemical fertiliser (t/ha)</th>
<th>Rate of use of organic fertiliser (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full-time cane grower</td>
<td>93.8</td>
<td>75.0</td>
<td>100.0</td>
<td>1.8</td>
<td>12.5</td>
</tr>
<tr>
<td>Aged full-time grower</td>
<td>53.6</td>
<td>63.6</td>
<td>63.6</td>
<td>1.2</td>
<td>21.9</td>
</tr>
<tr>
<td>Part-time grower</td>
<td>57.5</td>
<td>87.5</td>
<td>75.0</td>
<td>4.9</td>
<td>6.8</td>
</tr>
<tr>
<td>Petty grower</td>
<td>54.2</td>
<td>66.7</td>
<td>66.7</td>
<td>1.8</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Source: From the investigation.
The actual condition of unit crop and fertilisation management

The full-time grower of sugarcane compares 2004 with 2008 by unit crop, and most of the improvement is due to irrigation. Because the grower increased irrigation to 60%, per unit crop production became 58.9 t/ha (2004). However, in 2008, irrigation increased to 100% and per unit crop production was 93.8 t/ha. On the other hand, the aged full-time grower had 38.9% irrigation in 2004 and per unit crop production of 47.3 t/ha. However, in 2008, irrigation increased to 63.6% and per unit crop production increased to 53.6 t/ha.

Conclusion

Compared with the investigation in 2004, growers recognised the importance of fertilisation management in 2008. Therefore, crop yields have improved. The introduction of de-trashing equipment has reduced the grower's work burden. The grower can now carry out moulding and irrigation. However, commercial fertiliser is now the main source of fertiliser. Because the amount of compost has decreased, fertility has suffered. Moreover, the dead leaf is not returned to the farmland by introducing de-trashing equipment. Trash generated from de-trashing equipment is added to animal manure at the compost factory. This compost is available to only limited growers. Other growers must use chemical fertilisers. The present unit crop level is based on proper moulding and irrigation. Improving the fertilisation system leads to the possibility of improvement in unit crop. Continued research is necessary to stabilise production.

REFERENCES


CHANGEMENT DANS LA PRODUCTION DE CANNE A SUCRE APRES L’INTRODUCTION D’EQUIPEMENT DE DEPAILLAGGE:
UNE ETUDE DE CAS DE L’ILE D’IZENA

Par

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MOTS CLES: équipement de dépaillage, Problèmes d’une Population Vieillissante, Gestion de la Fertilisation.

Résumé

Ce papier discutera de la relation entre une population vieillissante de planteurs de canne à sucre sur l’île d’Izena, de l’introduction de procédures de dépaillage mécanique, des changements des pratiques de gestion du sol qui en découlent et des implications pour une productivité continue. La démographie agricole de la Préfecture d’Okinawa et de l’île d’Izena en particulier, entre 1995 et le
CAMBIO EN LA PRODUCCION DE CAÑA DE AZUCAR DESPUES DE LA INTRODUCCION DE EQUIPO PARA REMOCION DE HOJAS: ESTUDIO DEL CASO DE LA ISLA DE IZENA

Por

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KEYWORDS: Equipo Deshojador, Problemas de Envejecimiento de la Población, Manejo de la Fertilización.

Resumen

Este artículo discutirá las relaciones entre el envejecimiento de la población de los productores de caña de azúcar en la isla de Izena, la introducción de procedimientos mecánicos de deshoje, los cambios en las prácticas de manejo del suelo y las consecuencias para la productividad continua. La demografía de los agricultores en la Prefectura de Okinawa, e Isla de Izena en particular, entre 1995 y el día de hoy revela una disminución en la producción de caña de azúcar, un tamaño medio de las explotaciones de 1 hectárea o menos, y edad media del agricultor de 65 años o más. Las estadísticas también revelan que la sucesión de las tierras agrícolas y la agricultura, como ocupación de una generación a la siguiente, no es una tradición perdurable. Con el aumento de la edad, los cultivadores de caña de azúcar tienen más aceptación de los procedimientos mecánicos que alivian la carga física de su trabajo pero, como revela este estudio, tales procedimientos a veces pueden tener consecuencias inesperadas. Antes de la intervención mecánica, las hojas muertas (basura) eran retiradas de las cañas antes de su transporte a la fábrica, por lo que permanecían en la finca donde posteriormente eran devueltas al suelo como materia orgánica. Con los nuevos procedimientos de deshoje, la basura se va a la fábrica junto con la caña, donde es compostada como subproducto del proceso de molienda. Además, anteriormente cada explotación conservaba su propia basura para el compostaje, ahora el tratamiento mecánico en la fábrica se ha traducido en desigual distribución y suministro a los agricultores de la basura compostada. Esto ha suscitado preocupaciones sobre el deterioro de la fertilidad del suelo, disminución de la productividad e inadecuada conservación del agua debido a la falta de materia orgánica en el suelo.

jou présent, révèle une réduction de la production de canne à sucre, une taille moyenne d’exploitation d’un hectare ou moins, et un âge moyen d’agriculteur de 65 ans ou plus. Les statistiques révèlent aussi que la succession de terre agricole et de la culture d’une génération à l’autre n’est pas une tradition durable. Avec leur âge croissant, les planteurs de canne à sucre ont mieux accepté les procédures mécaniques qui réduisent l’aspect ardu de leur tâche, mais ces procédures peuvent parfois avoir des conséquences inattendues, comme révélé par ce papier. Avant la mécanisation, la paille était enlevée avant le transport des cannes vers l’usine et restait sur l’exploitation où elle était retournée au sol comme matière organique. Avec la nouvelle procédure de dépaillage, la paille est enlevée à l’usine et compostée comme un sous-produit de l’usinage. De plus, quand précédemment chaque exploitation conservait sa propre paille pour le compostage, la procédure mécanique à l’usine a résulté en une distribution inégale de la paille compostée aux producteurs. Cela a suscité des inquiétudes à propos de la baisse de fertilité du sol, de la diminution de productivité et de la conservation inadéquate d’eau, dues à un manque de matière organique dans le sol.
STUDY ON FARMLAND APPLICATION OF VINASSE FROM SUGARCANE MOLASSES

By

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KEYWORDS: Sugarcane Molasses, Pigment, Incubation Test, Tomato And Radish Cultivation.

Abstract
During bio-ethanol production from sugarcane molasses, large amounts of vinasse, which is strongly acidic with high COD and BOD, is produced as a by-product. Disposal of vinasse is one restrictive problem for sustainable bio-ethanol production. In this study, possible application of vinasse to farmland was investigated. First, the staple characteristics of vinasse were determined. Second, availability of nutrients such as nitrogen and potassium to crops and dynamics in the soil environment were studied in the laboratory and, thirdly, crop growth experiments were carried out in the field. In conclusion, 1) potassium is the most common nutrient in vinasse; 2) large amounts of chloride are also present; 3) high COD and pigment from rind of sugarcane were also observed. Farmland application of vinasse as a substitute for one third of the potassium showed no significant damage to the growth of red-raddishes and tomatoes. When large amounts of vinasse are applied to farmland as a substitute for the nitrogen in traditional chemical fertilisers, nitrogen deficiency symptoms, especially immediately after application, are expected. In addition, it is necessary to take into consideration the leaching of ions and the pigment in the vinasse for proper timing of application and soil conditions.

Introduction
Production of bioethanol from sugarcane molasses produces large amounts of vinasse, which is strongly acidic, and contains a high COD and BOD, as a by-product. Disposal is troublesome and restrictive for sustainable bio-ethanol production.

The objectives of this study were to determine the possibility of farmland application of vinasse based on the 1) characteristics of vinasse, 2) movement of organic nitrogen from vinasse in the soil, and 3) availability of potassium in vinasse by examining vegetables in laboratory and field experiments.

Materials and methodology

Vinasse
Vinasse was provided by Ryuseki Corporation in December, 2007. Vinasse was stored at room temperature until the experiments were performed.

Incubation test
The dynamics of nitrogen in the soil with vinasse or chemical fertiliser applied was investigated by an incubation experiment.

Shimajiri-maji soil (100 g) from the upland Miyako Island Branch of Okinawa Prefectural Agricultural Research Center was used in these experiments. Ammonium sulfate and vinasse (C/N ratio is 10.5) equivalent to 30 mg total nitrogen were added to the Shimajiri-maji soil. The soils were incubated at 30°C and soil moisture kept at 60%. NH₄-N, NO₃-N, and NO₂-N in the soil were measured every week.
Tomato and radish cultivation

The experiments were conducted at Kannodai, Tsukuba-shi, Ibaraki-ken, Japan. The experimental plots had been used to grow vegetables for several years. The tomatoes were planted on 12 May 2008 and harvested from 8 July 2008 to 29 August 2008. The red radishes were planted on 8 September 2008 and harvested on 12 November 2008.

Experiments (10 m² × 2)

(1) Tomato: control (only chemical fertiliser was applied), Red radish: control
(2) Tomato: vinasse (670 L/10a, 1/3 volume of potassium fertiliser replaced with vinasse) Red radish: control
(3) Tomato: control Red radish: vinasse (450 L/10a, 1/3 volume of potassium fertiliser replaced with vinasse)
(4) Tomato: vinasse (the same as experiment 2) Red radish: vinasse (the same as experiment 3)

Fertilisers:
Tomato: N: 30, P₂O₅: 20, K₂O: 30 kg/10a
Red-radish: N: 12, P₂O₅: 10, K₂O: 12 kg/10a

Measurements
Tomato: Weight of each fruit, Brix of fruit.
Radish: Weight of each radish leaf and root, Brix of radish root, and length and width of radish root.

Results and discussion

Characteristic of vinasse

The chemical propierties of vinasse are shown in Table 1. High contents of COD and TOC indicate a large amount of organic matter is included in vinasse. The characteristic of vinasse was content of COD Cr > content of COD Mn > content of BOD. BOD is the quantity of biodegradable organic matter. It was concluded that a large amount of decomposable organic matter was included in the vinasse. A problem is that some of the components, particularly those of darker colour are organic components which are difficult to decompose.

Table 1—Chemical proprieties of vinasse.

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>pH</td>
<td>4.28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COD Mn (mg/L)</td>
<td>81 900</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COD Cr (mg/L)</td>
<td>172 000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BOD (mg/L)</td>
<td>50 900</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOC (mg/L)</td>
<td>55 400</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K⁺ (mg/L)</td>
<td>17 000 (135 000)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cl⁻ (mg/L)</td>
<td>11 500 (11 400)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SO₄²⁻ (mg/L)</td>
<td>11 400</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S (mg/L)</td>
<td>3800</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total nitration (mg/L)</td>
<td>1976</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PO₄³⁻ (mg/L)</td>
<td>767 (120)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na⁺ (mg/L)</td>
<td>508 (423)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chloride</td>
<td>44 000</td>
<td></td>
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</tr>
</tbody>
</table>

*Content of dissolved elements are shown in parentheses

The content of potassium in vinasse is high and most of it is dissolvable. It is easy to use as a potassium fertiliser. However, the content of chlorine in vinasse was even higher, indicating we must carefully consider salinisation.
Dynamics of vinasse nitrogen in the soil

Figure 1 shows changes in inorganic nitrogen of the soil. The incubation test, clearly showed that the NH$_4$–N in soil treated with chemical fertiliser was almost completely converted into NO$_3$–N within two weeks.

On the other hand, the inorganic N decreased 50% in the soil during the initial two weeks when vinasse was applied, but 30% of NO$_3$–N increased in the soil over a period of 48 days when vinasse was applied.

Therefore, nitrogen deficiency, especially just after application, can be expected when large amounts of vinasse are applied to farmland.

Tomato and radish cultivation

The yields, individual weights and Brix of tomatoes in each experimental plot are shown in Figure 2. Many small and middle sized fruits less than 200 g were harvested from the vinasse plot such that the average weight of tomatoes in the vinasse plot was lighter than the tomatoes in the control plot. The numbers of tomatoes in the vinasse plot was greater than in the control plot. As a result, the yield of tomatoes in the vinasse plot was higher than in the control plot. In addition, the sugar content of the tomatoes in the vinasse plot was slightly higher than in the control plot.

The total weight of red radishes, the ratio of the weight of the roots and leaves, and the length and width of the roots are shown in Figure 3.

The highest weight of red radish was in the control (vinasse) plot. In the other three plots, there were no significant differences in total weight and root weight of red radishes. It is apparent that tomato and red radish are not affected by the application of vinasse and chemical fertiliser.
Conclusion

This study dealt with the influence of application of vinasse to the soil on dynamics of nitrogen and tomato and red radish growth. The results showed there was no significant damage to red radish and tomato growth with substitution of one third of the potassium fertiliser requirement being substituted by vinasse. This indicated that vinasse can be substituted for potassium fertilisers. However, when large amounts of vinasse are applied to farm land, it is suspected that nitrogen deficiency, especially just after application, can be expected.

Acknowledgement

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ETUDE DE L’APPLICATION DE LA VINASSE PROVENANT DE LA MÉLASSE DE CANNE À SUCRE SUR DES TERRES CULTIVÉES

Par

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MOTS CLÉS: Mélasse de Canne à Sucre, Pigment, Tests d’Incubation, Culture de Tomates et de Radis

Résumé

PENDANT la production de bioéthanol à partir de la mélasse de canne à sucre, de grosses quantités de vinasse, qui est un sous-produit très acide avec un DCO et DBO élevés, sont disponibles. La disposition de la vinasse est une contrainte pour une production durable de bioéthanol. L’application de la vinasse aux terres cultivées a été évaluée dans cette étude. Les caractéristiques de base de la vinasse ont d’abord été déterminées. Deuxièmement, la disponibilité des nutriments tels que l’azote et la potassium à la culture et leur mouvement dans le sol ont été étudiés en laboratoire et troisièmement, des essais de croissance de la culture ont été mis en place dans les champs. Pour conclure, 1) la potasse est le nutriments principal dans la vinasse; 2) de grosses quantités de chlorure sont aussi présentes; 3) une forte DCO et des pigments provenant de l’écorce de la canne sont aussi observés. L’application au champ de la vinasse comme substitut pour un tiers des besoins en potasse n’a pas eu d’effets négatifs sur la poussée des radis-rouge et des tomates. Quand de grosses quantités de vinasse sont appliquées dans les champs, comme substitut à l’azote chimique, des déficiences d’azote sont attendues, surtout juste après l’application. De plus, le lessivage des ions, le pigment dans la vinasse ainsi que les conditions du sol doivent être considérés pour le calendrier d’application.
ESTUDIO SOBRE LA APLICACIÓN DE VINAZA DE MELAZA DE CAÑA DE AZÚCAR EN TIERRAS CULTIVABLES

Por

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PALABRAS CLAVE: Melaza De Caña De Azúcar, Pigmento, Incubación, Prueba, Cultivo De Tomate Y Rábano.

Resumen
DURANTE la producción de bio-etanol a partir de melazas de caña de azúcar, se genera como subproducto gran cantidad de vinaza, la cual es fuertemente ácida y con elevadas DQO y DBO. La eliminación de la vinaza es un problema restrictivo para la producción sustentable de bio-etanol. En este estudio, se investigó la posible aplicación de vinazas a tierras de cultivo. En primer lugar, se determinaron las características básicas de la vinaza. En segundo lugar, se estudió en laboratorio la disponibilidad de nutrientes como el nitrógeno y el potasio para los cultivos y su dinámica en el entorno edáfico y, en tercer lugar, se llevaron a cabo en campo experimentos de crecimiento de cultivos. En conclusión, 1) el potasio es el nutriente más común en la vinaza; 2) también contiene grandes cantidades de cloruro; 3) se observó elevado DQO y pigmento de la corteza de la caña de azúcar. La aplicación de vinaza a tierras de cultivo de vinaza como un sustituto de un tercio del potasio no mostró ningún daño significativo sobre el desarrollo de rábanos rojos y tomates. Cuando grandes cantidades de vinaza son aplicadas a tierras cultivables como sustitución del nitrógeno contenido en los fertilizantes químicos tradicionales, se esperan síntomas de la deficiencia de nitrógeno, especialmente después de la aplicación. Además, es necesario tomar en consideración la lixiviación de los iones y el pigmento en la vinaza para encontrar el momento adecuado de aplicación y las condiciones del suelo.
A SUSTAINABLE FERTILISATION PROGRAM FOR A SUGAR FACTORY IN MEXICO: A PRINCIPLE FOR PRECISION AGRICULTURE

By


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KEYWORDS: Saccharum officinarum, Fertiliser Recommendation, Precision Agriculture, Conceptual Model.

Abstract

This work was carried out to determine site-specific fertiliser application rates for the different types of soil in which sugarcane is cultivated in the sugar factory ‘Presidente Benito Juárez’ in Mexico. Cartographic soil subunits were identified through interpretation of aerial photographs, field observations, and soil sampling to a depth of 1.2 m. In each subunit, the agrologic profiles were described, and physical and chemical analyses were done to classify the soil according to the World Soil Map. Fertilisation rates (FR) of N, P₂O₅, and K₂O for each soil subunit were estimated using a conceptual model. This model is based on the balance of nutrient demand of the crop, nutrients supplied by the soil, and fertiliser efficiency. To estimate demand, dry matter production and N, P, and K accumulation of the sugarcane aerial biomass were determined. P and K supply was calculated from the results of soil chemical analysis, plus the N contributions from crop residues and their management. Three major soil groups were found and classified as subunits. The FR for each soil subunit were (N, P₂O₅, K₂O kg/ha): 120–60–80 for Cambisol Fluvic (Eutric Clayic), Cambisol Endogleyic (Clayic Eutric) and Cambisol Stanic (Clayic Eutric); 120–70–80 for Cambisol Endogleyic Stanic (Eutric Ferric) and Gleysol Haplic (Eutric Clayic); 160–80–80 for Vertisol Gleyic Stanic (Eutric); and 120–80–80 for Vertisol Stanic (Eutric). Fertiliser rates were adjusted based on the expected sugarcane yields for each soil subunits and soil fertility maintenance. We also generated a map of FR for each sugarcane field to allow producers to locate the relevant rate.

Introduction

‘Presidente Benito Juárez’ sugar factory (PBJ) is the largest in the Tabasco state of Mexico. From 1996–97 to 2006–07 harvest seasons, sugarcane area increased from 11 031 to 16 488 ha; during this period, the sugarcane yield (TCH) averaged 63.3 TCH and sucrose yields 6457 kg/ha. TCH at PBJ were lower than the national average of 77 TCH (CAÑEROS, 2008).

The climate is hot and humid [Am(i)’g], with annual average temperature of 26°C, and annual average precipitation of 2163 mm, with an altitude of 11 m. The soils are alluvial and lacustrine, deep, with high clay contents, poor in organic matter, with problems of superficial and internal drainage, their pH is slightly acid (< 5.5) and the topography is flat.

In the PBJ, the cane is burned for its manual harvest, it is loaded mechanically, and the transport is in trucks and carts.

After the harvest, the straw is burnt, the chisel plough is used, fertiliser is applied mechanically or manually, and weeds are controlled with application of herbicides and manually. The fertiliser application rate of 120–60–60 kg/ha of N, P₂O₅ and K₂O has been used for more than
34 years, regardless of sugarcane variety, level of yields and soil type. There is a need to improve the efficiency of the production process to increase sugar yields and to reduce production costs to make the PBJ factory more profitable. The sustainable fertilisation program of IPBJ was thus implemented through an Integrated System to Recommend Rates of Fertilisers (SIRDF), and the results are presented in this paper.

**Methodology**

The study was conducted from June 2005 to October 2008, using the SIRDF methodology performed in 6 phases (Salgado et al., 2008);

1. Polygons of Thiessen. With the annual precipitation data (mm) of nine climatic stations of the zone (data average of 29 years), previously geo-referenced on the soils map, the areas with similar precipitation were defined, using an interpolation process to form the polygons of Thiessen (Tabios and Salas, 1985). This procedure was performed digitally using Arc Gis 9 (ESRI, 2007).

2. Study of soils. The soils cartography was performed using the photo-interpretation of aerial photography on a scale of 1:75,000, and this information was transferred to a topographic map with a scale of 1:30,000. With the description of 24 profiles and the results of the physical and chemical analyses of the horizons, the classification of soils was completed according to the World Reference Base for Soil Resources (IUSS Work group WRB, 2007). The map of soils with a scale of 1:30,000 was elaborated using Arc Gis 9 of the ESRI.

3. Soil Sampling. 150 sugarcane plantations were selected and geo-referenced. In each plantation, a composite sample of soil of 0 to 30 cm of depth was obtained. The sampling was done in a zigzag formation; with a soil auger, three sub-samples were taken on the furrow and three in the inter-furrow. The samples were mixed and homogenised, and 1.5 kg of sample was used for analysis. The physical and chemical determinations were made in the Laboratory of Analysis of Soils, Plants and Waters of the Campus Tabasco-CP, with the methods described by NOM-021-RECNAT (2001). The data K interchangeable and P-Olsen were used to calculate the soil supplies with the models:

\[
SUP-N = (DEM-N*0.10) + NDS,
\]

where:

NDS: nitrogen derived from the soil = 50 kg/ha, according to the TCH obtained without fertilisation (Salgado et al., 1994).

\[
SUP-P = [P \text{ soil } (\text{ppm}) \times Ec] + [(MSS) (\text{PPF} \times 10)],
\]

where:

MSS: Dry matter of the straw; it is considered that 60% of these residues are mineralised and are those that can contribute P and K to the cane culture.

PPF: Phosphorus concentration of the foliar analysis (%).

Ec: the index of efficiency of the culture; it indicates that for each part per million (ppm) of P-Olsen, the culture absorbs 1.7 kg of P of the soils (Rodriguez, 1993).

\[
SUP-K = [K \text{ soil } (\text{ppm}) \times CK] + [(MSS) (\text{PKF} \times 10)],
\]

where:

PKF: Potassium concentration of the foliar analysis (%).

CK: the efficiency of potassium absorption; it indicates ppm of K interchangeable that the culture absorbs according to the type of soil, which is 1.4 for loam soils and 1.3 for argillaceous soils (Rodriguez, 1993).

4. The sampling of aerial biomass (stalk, tops and dry leaves) was conducted at 11 months of age in the same sites where the soils samples were obtained. A linear metre of cane was harvested and weighed (kg), the biomasses were separated into straw (top+dry leaves) and stalk, and were sampled separately; 400 g of each sample were dried in the oven to determine dry matter. The samples were ground to 2 mm, the chemical analyses of N, P and K were made...
in the LASPA-Campus Tabasco, with the methods of Jones et al. (1991). The dry matter of stalk and straw was used to calculate the demand of N, P and K for soil subunits.

\[
\text{DEM (kg/ha)} = \frac{\text{MSS (kg/ha)}}{100} \times (\% \text{ nutrient straw}) + \frac{\text{MSST (kg/ha)}}{100} \times (\% \text{ nutrient stalk})
\]

where:

MSST = Dry matter of the stalk

The weight of stalk was used to calculate the TCH. The potential TCH corresponded to the maximum yields of cane obtained by soil subunits.

5. Determine fertiliser rates using the conceptual model; Rate of Fertiliser = (Demand - Soil Supplies)/Efficiency (Rodriguez, 1993).

The efficiency for N is 50% (Garcia, 1984), for phosphorus 30 and 40% in argillaceous and loam soils respectively, and for potassium 60% in argillaceous soils (Salgado et al., 2005; Bolio et al., 2008).

6. Generate recommendations for a fertiliser program, considering soil subunits, soil pH, fertiliser source and costs of fertilisers (Salgado et al., 2006).

Fig. 1—Areas of differing precipitation near the PBJ factory’s supply zone.

Results and discussion

Thiessen polygons

Five polygons were identified, with precipitation ranging from 1640 to 2227 mm/year (Figure 1). These defined areas are useful for scheduling the harvest and irrigation in the study area (Tabios and Salas, 1985), as areas with more precipitation require less irrigation.
Soil study

Figure 1 also presents the soil subunits found in the study area. The specific soil subunits identified were Cambisol Fluvic (Eutric Clayic), Cambisol Endogleyic (Clayic Eutric), Cambisol Stanic (Clayic Eutric), Cambisol Endogleyic Stanic (Eutric Ferric), Gleysol Haplic (Eutric Clayic), Vertisol Gleyic Stanic (Eutric), and Vertisol Stanic (Eutric) (IUSS Grupo de Trabajo WRB, 2007).

Compaction in upper soil horizons, high clay content, humidity retention, low infiltration, little soil slope, low CEC, medium to low organic matter content and assimilable phosphorus, and slightly acidic pH are the main soil factors limiting sugarcane yields in PBJ factory’s supply zone.

Fertilisation rates

The demand for N and K showed great variation between soil subunits, contrary to the supply of these nutrients, indicating possible extractive differences between cultivated varieties of cane; when combined with the low yield, it produced an underestimation of the demand for N, P and K (Table 1).

TCH of soils described above is (in decreasing rank): Vertisol > Cambisol > Gleysol. However, Cambisols with high clay content have reduced TCH. The nutrient supply from these soils is K>N>P (Table 1).

<table>
<thead>
<tr>
<th>Soils subunits</th>
<th>TCH</th>
<th>Demand (stalk+straw) (kg/ha)</th>
<th>Soils supplies (kg/ha)</th>
<th>Rates of conceptual model (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>N</td>
<td>P</td>
<td>K</td>
</tr>
<tr>
<td>Cambisol Fluvic (Eutric Clayic)</td>
<td>63.81</td>
<td>77.6</td>
<td>30.2</td>
<td>29.2</td>
</tr>
<tr>
<td>SD</td>
<td>21.41</td>
<td>17.4</td>
<td>3.2</td>
<td>52.9</td>
</tr>
<tr>
<td>Cambisol Endogleyic (Clayic Eutric)</td>
<td>54.79</td>
<td>55.0</td>
<td>27.0</td>
<td>111.2</td>
</tr>
<tr>
<td>SD</td>
<td>12.49</td>
<td>4.5</td>
<td>2.7</td>
<td>100.5</td>
</tr>
<tr>
<td>Cambisol Endogleyic Stanic (Eutrico -Férrico)</td>
<td>63.24</td>
<td>75.4</td>
<td>31.9</td>
<td>8.9</td>
</tr>
<tr>
<td>SD</td>
<td>24.60</td>
<td>16.7</td>
<td>3.2</td>
<td>3.6</td>
</tr>
<tr>
<td>Cambisol Stanic (Clayic Eutric)</td>
<td>59.12</td>
<td>63.7</td>
<td>38.9</td>
<td>11.7</td>
</tr>
<tr>
<td>SD</td>
<td>21.25</td>
<td>14.5</td>
<td>2.1</td>
<td>1.4</td>
</tr>
<tr>
<td>Gleysol Haplic (Eutric Clayic)</td>
<td>57.82</td>
<td>72.3</td>
<td>27.6</td>
<td>98.3</td>
</tr>
<tr>
<td>SD</td>
<td>17.09</td>
<td>12.0</td>
<td>3.2</td>
<td>104.6</td>
</tr>
<tr>
<td>Vertisol Gleyic Stanic (Eutric)</td>
<td>68.50</td>
<td>64.0</td>
<td>31.1</td>
<td>168.4</td>
</tr>
<tr>
<td>SD</td>
<td>26.83</td>
<td>12.1</td>
<td>6.0</td>
<td>165.7</td>
</tr>
<tr>
<td>Vertisol Stanic (Eutric)</td>
<td>62.59</td>
<td>68.1</td>
<td>30.1</td>
<td>49.6</td>
</tr>
<tr>
<td>SD</td>
<td>22.03</td>
<td>14.0</td>
<td>3.9</td>
<td>79.6</td>
</tr>
</tbody>
</table>

SD: Standard deviation
The 0.40 straw/stalk ratio indicates a poor crop development, with stalk showing a lower nutrient concentration for Ca and Mg (data not shown).

In the straw, the concentrations of N, P, K and Mg were low in comparison with those reported for ‘Santa Rosalía’ factory (Salgado et al., 2005); indicating that the soils are of low fertility.

The fertiliser rates estimated from the conceptual model (Table 1) were lower in P and K than the recommended rate of 120–60–60 used by the PBJ factory (Rojas et al., 1984), and the rates of fertilisers 240–60–240, 240–30–240, 240–30–120, and 240–60–120, recommended for yields 100 to 120 t/ha in PBJ sugar factory (Ortiz, 2005).

If the drainage of the soils is improved, TCH will be increased; for that reason, rates of the conceptual model were fitted on the basis of the potential TCH (Table 2), with the contents of P and K of each soil subunit.

The experimental results obtained through field tests indicated that there is no response to higher rates of 80 kg/ha for both K₂O and P₂O₅ (Salgado et al., 2003). The fertiliser sources 17–17–17 and Urea are recommended in order to supply the nutrients required by the crop (Table 2), and this option is a more economic fertiliser source (Salgado et al., 2006).

Figure 2 shows the distribution of rates of fertilisation adjusted for the PBJ factory supply zone.

### Table 2—Rates of fertilisation recommended for the PBJ factory’s supply zone, according to the soil subunits of ground; yield and cost.

<table>
<thead>
<tr>
<th>Soil subunits</th>
<th>Potential TCH</th>
<th>Fertiliser rate adjusted</th>
<th>Options of fertiliser sources ($/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(kg/ha)</td>
<td>N  P₂O₅ K₂O</td>
<td>1: U+SPT+KCl</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2: Complex 20–10–10–EM</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3: U+Triple 17-EM</td>
</tr>
<tr>
<td>Cambisol Fluvic (Eútrico Arcílico)</td>
<td>85</td>
<td>120 60 80</td>
<td>260.8 U+130.4 SPT+133.3 KCI 5137.20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>600 C 20–10–10–EM +33 KCI 5633.50</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>130 U+353 Triple 17-EM +33 KCI 4789.80</td>
</tr>
<tr>
<td>Cambisol Endogleylic (Arcillo Eutrico)</td>
<td>66</td>
<td>120 60 80</td>
<td>260.8 U+130.4 SPT+133.3 KCI 5137.20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>600 C 20–10–10–EM +33 KCI 5633.50</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>130 U+353 Triple 17-EM +33 KCI 4789.80</td>
</tr>
<tr>
<td>Cambisol Endogleylic Stanic(Eutric Ferric)</td>
<td>85</td>
<td>120 70 80</td>
<td>260.8 U+152 SPT+133.3 KCI 5414.90</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>600 C 20–10–10–EM +25 SPT+33 KCI 5953.50</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>108 U + 411 Triple 17-EM 4868.20</td>
</tr>
<tr>
<td>Cambis Sol Stanic (Clayic Eutric)</td>
<td>80</td>
<td>120 60 80</td>
<td>260.8 U+130.4 SPT+133.3 KCI 5137.20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>600 C 20–10–10–EM +33 KCI 5633.50</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>130 U+353 Triple 17-EM +33 KCI 4789.80</td>
</tr>
<tr>
<td>Gleysol Haplic (Eutric Clayic)</td>
<td>75</td>
<td>120 70 80</td>
<td>260.8 U+152 SPT+133.3 KCI 5414.90</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>600 C 20–10–10–EM +25 SPT+33 KCI 5953.50</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>108 U + 411 Triple 17-EM 4868.20</td>
</tr>
<tr>
<td>Vertisol Gleyic Stanic (Eutric)</td>
<td>94</td>
<td>160 80 80</td>
<td>347.8 U+173.5 SPT+133.3 KCI 6692.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>800 C 20–10–10–EM 6512.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>174 U + 470 Triple 17-EM 6001.00</td>
</tr>
<tr>
<td>Vertisol Stanic (Eutric)</td>
<td>85</td>
<td>120 80 80</td>
<td>260.8 U+173.5 SPT+133.3 KCI 5688.80</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>120-83-80 600 C 20-10-10-EM +50 SPT+33 KCI 6273.50</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>87 U+470 Triple 17-EM 5350.70</td>
</tr>
</tbody>
</table>

U: Urea, SPT: Triple Calcium Superphosphate, KCl: Potassium chloride, 20-10-10 EM and Triple 17: Complex enriched with micronutrients.

The costs are calculated to 01/08/2008 in Mexican pesos (1 USD=12.5 Mexican pesos).
**Conclusions**

Five Thiessen polygons were established based on precipitation for the PBJ factory supply zone. Soil subunits identified in the study area are Cambisol Fluvic (Eutric Clayic), Cambisol Endogleyic (Clayic Eutric), Cambisol Stanic (Clayic Eutric), Cambisol Endogleyic Stanic (Eutric Ferric), Gleysol Haplic (Eutric Clayic), Vertisol Gleyic Stanic (Eutric) and Vertisol Stanic (Eutric). The fertility diagnosis established that soils in the PBJ factory supply area have low fertility, the limiting factors being: compaction, excessive clay, humidity, and superficial acidity. Biomass sampling revealed a straw/stalk ratio of 0.40 which is considered inadequate and accounts for the low TCH. Four fertiliser rates were formulated, which take into account soil subunit features and a precision agriculture map generated for the PBJ factory supply zone.

**Acknowledgements**

Thanks are extended to Fundación Produce Tabasco, A.C. and the Committee of Production and Sugarcane Quality of the PBJ factory’s for its economic and logistical support.
REFERENCES


UN PROGRAMME DE FERTILISATION RAISONNÉE POUR UNE INDUSTRIE SUCRIERE AU MEXIQUE: UNE BASE POUR UNE AGRICULTURE DE PRECISION

Par

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MOTS-CLES: Saccharum officinarum, Conseil en Fertilisation,
Agriculture de Précision, Model Conceptuel

Résumé

EL PROGRAMA DE FERTILIZACIÓN SOSTENIBLE PARA UNA FÁBRICA DE AZÚCAR EN MÉXICO: UN PRINCIPIO PARA AGRICULTURA DE PRECISIÓN

Por


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PALABRAS CLAVE: Saccharum officinarum, Recomendación de Fertilizante, Agricultura de Precisión, Modelo Conceptual.

Resumen

Este trabajo realizó para determinar índices de aplicación de fertilizante para los diversos tipos de suelo en que se cultiva caña de azúcar en la fábrica ‘Presidente Benito Juárez’ en México. Se identificaron subunidades cartográficas de suelo, por medio de la interpretación de fotografías aéreas, observaciones de campo y muestreos de suelo a una profundidad de 1.2 m. En cada subunidad, los perfiles agrológicos se describieron y se realizaron análisis físicos y químicos para clasificar el suelo de acuerdo al Mapa Mundial de Suelo. Se estimaron los índices de fertilización (FR) de N, P₂O₅ y K₂O para cada subunidad de suelo utilizando un modelo conceptual. Dicho modelo se basa en el balance de demanda de nutrientes del cultivo, nutrientes aportados por el suelo y eficiencia del fertilizante. Para estimar la demanda, se determinó la producción de materia seca y acumulación de N, P y K en la biomasa aérea de la planta de caña de azúcar. Se calculó el aporte de P y K de los resultados del análisis químico de suelo y el del N proporcionado por los residuos del cultivo y su manejo. Se encontraron tres grandes grupos de suelos y se clasificaron en subunidades. El índice para cada subunidad de suelo fue (N, P₂O₅, K₂O kg/ha): 120–60–80 para Cambisol Fluvic (Eutric Clayic), Cambisol Endogleyic (Clayic Eutric) y Cambisol Stanic (Clayic Eutric); 120–70–80 para Cambisol Endogleyic Stanic (Eutric Ferric) y Gleysol Haplic (Eutric Clayic); 160–80–80 para Vertisol Gleyic Stanic (Eutric); y 120–80–80 para Vertisol Stanic (Eutric). Los índices de fertilizante se ajustaron con base en los rendimientos esperados para cada subunidad de suelo y el mantenimiento de la fertilidad del suelo. Además, se generó un mapa del índice FR de cada plantación para permitir a los productores localizar el índice de su interés.
DIVERSIFICATION OF SUGARCANE VARIETIES FOR CATTLE FEED AND SUSTAINABILITY

By

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KEYWORDS: Cattle Feed, Digestibility, Dry Matter, Soils, Abiotic Stress.

Abstract

The paper reports results of a study of 44 sugarcane genotypes, evaluated as cattle feed, at 13 months of age, in the first ratoon crop, at Villa Clara–Cienfuegos Territorial Sugar Cane Research Station and the Sancti Spíritus National Breeding Center in Cuba. Fourteen traits were evaluated by means of multivariate analyses (Principal Components and Discriminant Function), and also a simulation was conducted of agro-ecological regionalisation for the allocation of the sugarcane varieties according to the main limiting factors (drought and poor drainage) on a cattle producing farm. Results showed that the variables, percentage of stalk fresh weight (% of stalks) and of tops (% of tops), had high influence in the first principal component, whereas the genetic disease (smut and rust) resistance had high influence in the second component. It should be pointed out that the percentage of digestibility of the dry matter showed very little variability, which indicates a high stability of this trait. The Discriminant Function Analysis allowed classification of cultivars into three groups: varieties of low forage value (below 40% digestibility of the dry matter), varieties of intermediate forage value (between 40–50%) and varieties of high forage value (above 50% digestibility). Results allowed the recommendation of 21 new genotypes, characterised by their resistance to main diseases and their high forage value, and nine were superior to the control My5514, four suitable for waterlogging stress and three for drought stress. The simulation of the agro-ecological regionalisation enabled spatial location and modelling for the appropriate establishment of individuals, in agreement with their digestibility, tolerance to the two environmental stresses (waterlogging and drought) and their disease resistance.

Introduction

Population growth is a problem in the world today. It is probable that population will increase to 830 000 in 2025 (FAO, 1998).

This must be viewed in the context of a decrease in the area of arable land committed to food production because of competition for application of pasture and grain crops to energy production.

Mankind has knowledge and technologies to confront this crisis, but policies of unequal distribution of wealth have resulted in some negative environmental and social impacts (FAO, 1996).

Sugarcane constitutes an alternative to be used for animal nutrition. Countries like Colombia, Brazil and Costa Rica maintain that the technical and biological basis exists to use sugarcane to replace cereals in intensive animal production systems, thus allowing the release of great quantities of foodstuffs for mankind.
This paper was developed to characterise a group of varieties of sugarcane for use as animal food and for identifying suitable agro-ecological environments for them to be used as cattle producing units.

**Materials and methods**

The study was developed in two provinces of the country (Villa Clara and Sancti Spíritus) at the Sugar Companies Ifraín Alfonso and Melanio Hernández, in soil Eutric Cambisol (FAO – UNESCO, 1994).

Forty-four recently recommended new varieties of sugarcane from the Sugarcane Research National Institute for Sugar Production were studied.

The plots were of 64 m$^2$, with five replications in the first ratoon crop harvested at 13 months of age. Fourteen variables relating to crop morphology and the probable relationship with the digestibility of the biomass were evaluated.

Genetic resistance against two important diseases, brown rust and sugarcane smut, was also quantified.

The digestibility of the dry matter of each variety was determined by the *in vitro* technique of KOH (Kesting, 1977).

The statistical analysis was performed using the multivariate analyses of Principal Components and Discriminant Functions, in which the digestibility of the dry matter was used like a group variable, with three groups: $<40\%$, $>50\%$ and the correspondent interval.

The varietal performance was assessed by comparing means of the percentage digestibility of dry matter with the control variety My5514.

The software MapInfo 8.0 was used for the agro-ecological zoning simulation on a cadastral base map of 1:10000 scale.

The utilisation of 90% of the area of the unit was assumed for cattle raising, and the distribution of the nutrition of the cattle mass was distributed in the following way: 57% improved pasture land, 26% King Grass (CT–115) and 17% sugarcane for animal nutrition.

We also took into account soil types in relation to the impact of physical properties such as soil depth, water holding capacity and drainage capacity on the suitability for production of the various sugarcane varieties.

Then we established the following premises: to obtain a fodder balance for fattening 1880 head of bulls to a finished live weight of 450 kg, equivalent to 1692 units of greater cattle (UGC), that represent one charge of two cattle per ha.

We considered that sugarcane fulfills 43.7% of the requests for foodstuff in the period of minor availability (212 days).

**Results and discussion**

Of the 14 variables used for the evaluation of the use of the variety of cane as an alternative for the feeding of cattle, Principal Components Analysis indicated that 9 of the variables across three factors contributed 64% of the total variation (Table 1) and they were considered sufficient in that objective.

The proportion of variance explained by top stems and the stems of the total biomass allowed separation of the varieties and allowed recommendation of more disease resistant and productive varieties than the standard commercial clone.

In the second component, the digestibility of the dry matter was ranked as the next most important variable (Eigenvector 0.43) after the previous variables.

These results explained enough of the variation to allow easy selection of suitable varieties.
Table 1—Eigenvalues and Eigenvectors from Principal Components Analysis.

<table>
<thead>
<tr>
<th></th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Eigenvalues</strong></td>
<td>2.688</td>
<td>1.865</td>
<td>1.231</td>
</tr>
<tr>
<td>% total variance</td>
<td>29.870</td>
<td>20.722</td>
<td>13.680</td>
</tr>
<tr>
<td>% total variance aggregate</td>
<td>29.870</td>
<td>50.592</td>
<td><strong>64.272</strong></td>
</tr>
<tr>
<td><strong>Eigenvectors</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stems percentage</td>
<td>0.915</td>
<td>0.087</td>
<td>0.160</td>
</tr>
<tr>
<td>Top stems percentage</td>
<td><strong>-0.949</strong></td>
<td>0.022</td>
<td>-0.008</td>
</tr>
<tr>
<td>Digestibility dry matter</td>
<td>0.286</td>
<td>0.427</td>
<td>-0.252</td>
</tr>
<tr>
<td>Brix</td>
<td>0.146</td>
<td>0.054</td>
<td>0.043</td>
</tr>
<tr>
<td>Pol %</td>
<td>0.183</td>
<td>-0.075</td>
<td>0.017</td>
</tr>
<tr>
<td>Thorns</td>
<td>0.131</td>
<td>0.340</td>
<td><strong>0.768</strong></td>
</tr>
<tr>
<td>Habit of growth</td>
<td>-0.083</td>
<td>0.015</td>
<td><strong>-0.874</strong></td>
</tr>
<tr>
<td>Smut</td>
<td>-0.006</td>
<td><strong>0.829</strong></td>
<td>0.207</td>
</tr>
<tr>
<td>Rust</td>
<td>0.045</td>
<td><strong>0.882</strong></td>
<td>0.041</td>
</tr>
</tbody>
</table>

The result of 76.7% of good classification from Discriminant Function Analysis (Figure 1) corroborated the importance of the morphologic and physiological variables that were used in the evaluation of the varieties as possible indicators of the fodder value.

The results agree with those of Suárez (2002) who considered varieties to be acceptable for the nutrition of cattle if digestibility of dry matter were greater than 50%.

Twenty one of the 44 genotypes showed more than 50% digestibility of dry matter and tolerance to the principal sugarcane diseases (Table 2).

These can be used for animal nutrition (Jorge et al., 2002). Thus a range of suitable varieties of sugarcane are available for commercial production.

The dendrogram representative of automatic classification of the 21 cultivars presenting higher digestibility of dry matter over 50% allowed the observation of two groups, which passed the threshold of 2.36. The first (group 2), that included the tester cultivar My5514, was characterised by a higher phenological relation of top and dry leaves than the other group, for which the digestibility was higher (Figure 2).
Table 2—Characteristics of the 21 varieties that were similar or better than the control variety for digestibility %.

<table>
<thead>
<tr>
<th>Variety</th>
<th>DMS</th>
<th>IRT</th>
<th>SP</th>
<th>STP</th>
<th>Rust brown</th>
<th>Smut</th>
</tr>
</thead>
<tbody>
<tr>
<td>C89-176</td>
<td>56.63</td>
<td>109.75</td>
<td>12.43</td>
<td>6.26</td>
<td>I</td>
<td>I</td>
</tr>
<tr>
<td>B80250</td>
<td>56.28</td>
<td>109.07</td>
<td>11.70</td>
<td>9.50</td>
<td>R</td>
<td>I</td>
</tr>
<tr>
<td>C90-501</td>
<td>55.30</td>
<td>107.17</td>
<td>22.90</td>
<td>9.00</td>
<td>R</td>
<td>I</td>
</tr>
<tr>
<td>C86-12</td>
<td>55.30</td>
<td>107.17</td>
<td>10.60</td>
<td>9.50</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Co997</td>
<td>54.80</td>
<td>106.20</td>
<td>29.00</td>
<td>10.10</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>C132-81</td>
<td>54.40</td>
<td>105.43</td>
<td>18.50</td>
<td>5.30</td>
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<td>R</td>
</tr>
<tr>
<td>C90-530</td>
<td>54.30</td>
<td>105.23</td>
<td>20.50</td>
<td>4.10</td>
<td>I</td>
<td>R</td>
</tr>
<tr>
<td>C87-252</td>
<td>54.07</td>
<td>104.79</td>
<td>24.70</td>
<td>9.50</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>C92-203</td>
<td>53.30</td>
<td>103.29</td>
<td>10.70</td>
<td>7.60</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>C137-81</td>
<td>53.20</td>
<td>103.10</td>
<td>14.10</td>
<td>4.90</td>
<td>R</td>
<td>R</td>
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<tr>
<td>C89-161</td>
<td>53.00</td>
<td>102.71</td>
<td>13.30</td>
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<td>R</td>
<td>R</td>
</tr>
<tr>
<td>C87-51</td>
<td>52.96</td>
<td>102.64</td>
<td>14.46</td>
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<td>52.40</td>
<td>101.55</td>
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<td>12.70</td>
<td>I</td>
<td>I</td>
</tr>
<tr>
<td>C85-203</td>
<td>51.90</td>
<td>100.58</td>
<td>12.20</td>
<td>6.80</td>
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<td>I</td>
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<tr>
<td>C86-503</td>
<td>51.80</td>
<td>100.39</td>
<td>14.10</td>
<td>6.70</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>My5514*</td>
<td>51.60</td>
<td>100.00</td>
<td>22.80</td>
<td>6.30</td>
<td>S</td>
<td>R</td>
</tr>
<tr>
<td>C90-317</td>
<td>51.33</td>
<td>99.48</td>
<td>11.60</td>
<td>6.16</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>C95-416</td>
<td>51.32</td>
<td>99.46</td>
<td>15.73</td>
<td>4.70</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>C128-83</td>
<td>50.60</td>
<td>98.06</td>
<td>13.20</td>
<td>5.50</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>C91-356</td>
<td>50.41</td>
<td>97.69</td>
<td>19.50</td>
<td>5.56</td>
<td>R</td>
<td>I</td>
</tr>
<tr>
<td>C86-165</td>
<td>50.32</td>
<td>97.52</td>
<td>19.76</td>
<td>7.90</td>
<td>I</td>
<td>R</td>
</tr>
<tr>
<td>C88-553</td>
<td>50.03</td>
<td>96.96</td>
<td>18.30</td>
<td>3.73</td>
<td>I</td>
<td>R</td>
</tr>
</tbody>
</table>

DMS = Digestibility dry matter, IRT = Increment in relation to the control varieties, SP = Stems percentage, STP = Top stems percentage, R = Resistant, I = Intermediate, S = Susceptible, *= Control variety.

Fig. 2—Dendrogram of the classification of the cultivars.
According to Paretas (1990), 40% of the Cuban cattle area is susceptible to drought stress, because of low water holding capacity of the soils, and this contrasts with the 30% of the area that is poorly drained (Figure 3).

Nine of the varieties from this study can be used for animal nutrition in areas of cane production subject to abiotic stress, C89-176, C86-503, C86-12, C86-165, C90-530 to drought and C137-81, C86-503, C132-81, C86-12, Co997 for poor drainage, and they are likely to be important in those regions.

Simulation of zoning agro-ecological
The varieties, C86-12 and C132-81, were located in a 40.4 ha area of bad drainage and C90-530 in an adjoining 36.1 ha, also with poor drainage (Figure 4). Areas of 30.3 and 34.2 ha of soils potentially affected by drought were planted to C90-317 and C89-176, respectively (Figure 4).
Conclusions

- The percentage of fresh weight of the stem and percentage of the fresh weight of the top stem in sugarcane biomass, along with resistance to rust and smut, were the variables which best characterized the studied population for variability in the percentage of dry matter digestibility. This enabled the selection of varieties for use in the animal nutrition.

- The classification of the varieties for the percentage of the digestibility of dry matter showed that 21 of the 44 varieties had more than 50% digestibility, making them suitable for use in the nutrition of cattle.

- The agro-ecological zoning allowed the varieties to be recommended for locations that matched tolerance of drought or waterlogging stresses.

REFERENCES


DIVERSIFICATION DES VARIETES DE CANNE A SUCRE POUR L’ALIMENTATION ANIMALE ET LA DURABILITE

Par

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Resume

Ce papier rela te le s r é sultats d’u ne étude su r 44 génotypes de canne à sucre, évalués pour l’alimentation animale à l’âge de 13 mois en première repousse, à la station territoriale Cienfuegos de recherche sur la canne à sucre de Villa Clara et au centre national de création variétale de Sancti Spiritus à Cuba. 14 traits furent évalué s a u moyen d’analys es multivar iées (Analyses en composantes principales et discr iminante) et une sim ulation de ré gionalisation agro-écologique fut aussi réalisé é. Cette d é rnière co ncerait l’allocation des variétés se lon le s f acteurs lim itants principaux (sécheresse et faible drainage) sur une ferme d’élevage. Les résultats montrèrent que les variables, teneurs en eau des tiges (%) et d es sommets (%) avaient une influence importante sur la première composante principale, tandis que la résistance aux maladies (rouille et charbon) avait une
influence importante sur la seconde composante. On a remarqué que le pourcentage de digestibilité de la matière sèche pré sentait peu de variabilité, montrant ainsi une grande stabilité de ce trait.

L’analyse discriminante a permis de classer les variétés en trois groupes: des variétés à valeur fourragère faible (en dessous de 40% de digestibilité de la matière sèche), les variétés à valeur fourragère intermédiaire (entre 40% et 50%) et les variétés à haute valeur (supérieures à 50% de digestibilité). Les résultats permirent d’établir des recommandations pour 21 nouveaux génotypes caractérisés par leur résistance aux principales maladies et leur faible valeur fourragère, pour 9 variétés qui étaient supérieures au témoin My5514, pour 4 variétés résistantes à l’excès d’eau et pour 3 variétés résistantes à la sécheresse. La simulation de la zonification agro-écologique a permis une distribution spatiale des individus appropriés à chaque localité, pour leur digestibilité, leur tolérance à deux stress environnementaux (excès d’eau et stress hydrique) et leur résistance aux maladies.

DIVERSIFICACIÓN DE LAS VARIEDADES DE CAÑA DE AZÚCAR PARA EL GANADO, ALIMENTACIÓN Y LA SOSTENIBILIDAD

Por

H. JORGE, O. SUÁREZ, H. GARCÍA, I. JORGE y L. BENITEZ

PALABRAS CLAVES: Ganado, Alimentación, Suelos, Estrés Abiótico.

Resumen

SE PRESENTAN los resultados del estudio de 44 genotipos de caña de azúcar evaluados con 12–14 meses de edad en la cepa de retoño en suelos Pardos con carbonato (Cambio eútrico) de la Estación Territorial de la Caña de Azúcar (ETICA) Villa Clara-Cienfuegos y el Centro Nacional de Hibridación de Sancti Spíritus (CNH), con vista a su recomendación para la alimentación animal. Se evaluaron 14 caracteres mediante Análisis Multivariado (Componentes Principales y Factorial Discriminante), también se realizó una simulación de zonificación agroecológica para la ubicación de las variedades de caña de azúcar, de acuerdo a los principios factores limitantes (sequía y mal drenaje) de una unidad productora de ganado vacuno. Los resultados reflejan que las variables porcentaje del peso fresco del tallo (% de tallo) y el cogollo (% cogollo) tuvieron una alta influencia en la primera componente, mientras que la resistencia genética a las enfermedades (carbón y roya) lo fueron para la segunda. Es de destacar que el porcentaje de digestibilidad de la materia seca muestra muy poca variabilidad, lo que puede indicar un alto estabilidad de este carácter. El Análisis Discriminante permitió clasificar los cultivares en tres grupos: Variedades de bajo valor forrajero (menor de 40% de la digestibilidad de la materia seca), Variedad de medio valor forrajero (entre 40–50%) y Variedades de alto valor forrajero (mayor de 50%). Los resultados permitieron recomendar 21 nuevos genotipos caracterizados por su resistencia a las principales enfermedades y su alto valor forrajero, donde 9 de ellas se adaptan a condiciones de estrés ambiental. La simulación de la zonificación agroecológica permitió la ubicación espacial y la modelación en cuanto al correcto establecimiento de los individuos en correspondencia a su tolerancia con los factores limitantes antes mencionados.
STRATEGIES FOR THE OPTIMAL USE OF NITROGEN FERTILISERS IN THE SUGARCANE CROP IN GUATEMALA

By

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KEYWORDS: Nitrogen, Optimisation, Green Manure, N Biological Fixation.

Abstract

The objective of this work is to present practical criteria that will help sugarcane growers to optimise their investment in nitrogen fertilisers in the sugarcane crop in Guatemala. The importance of this objective is in relation to the general increase of fertiliser price and particularly of nitrogen fertiliser. The criteria are based on knowledge of crop response to N application in the region after 14 years of experience in research on the topic. Crop N response is a function of cane yield, soil fertility, crop age or crop cycle and other variables associated with agronomical practices and soil condition. As a result, N rate used in sugar mills’ fertilisation programs can be adjusted by comparing the current relation of kg of nitrogen per tonne of cane (N:TC), with reference ratios recommended for different soils according to organic matter content (OM) and other factors. Besides, N rates must be adjusted to fertiliser and sugar price for different production groups. As an alternative to reduce dependence on nitrogen fertilisers, there are practices that must be taken into account and be optimised in the short term. These practices consist of usage of species of green manure adapted to the intercropping system, the use of co-products and, in the mid and long term, there is potential for N biological fixation in the sugarcane crop.

Introduction

Nitrogen use in Guatemala is generalised in the sugarcane production as in most cane producing countries. In Guatemala, it is estimated that, in the 2006–07 harvest season, there were approximately 20 000 tonnes of nitrogen applied over 210 000 hectares (Pérez, 2007). The nitrogen fertiliser item is gaining importance in the crop production cost because of the increase in nitrogen fertiliser price that, only in the past year (2008), increased over 80% while the sugar price stood relatively constant. Under these circumstances, sugar mills have seen themselves forced to make adjustments in their budgets, requiring an effective and judicious use of fertilisers to ensure maximum advantage of investment.

The objective of this work is to present some practical strategies for sugarcane growers to support their decision-making process to maximise investment on nitrogen fertilisers, beginning with current fertilisation programs and presenting some options that will help in the future to reduce dependence on chemical fertilisers.

Generalities of Guatemala sugarcane region and yield potential

Based on the physiographic features that respond to a natural landscape of plain terrain and foothill, there is a gradient in terms of temperature, amount of rainfall, solar radiation, forms and slopes of terrain and presence of Allophane in soils, varying from the proximity to the mountain
chain towards the Pacific Ocean, in a North–South direction. These gradients are captured with regional altitudinal stratification and are expressed in yield potentials of sugarcane as shown in Table 1. Table 1 shows that the higher yield potentials are in the lower zones of the region decreasing with altitude where there is lower temperature, more cloudiness associated with higher rainfalls, soils with undulating relief, and there are greater amounts of Allophane clays (Andisols).

There is a particular relationship between OM and cane yield under the sugarcane growing area of Guatemala. The OM contents are greater in the middle and higher zones of the region in which Andisol soils predominate and decrease in the coastal zone in Mollisol and Entisol soils. Although amounts of OM in Andisol soils are higher, they are not associated with greater yields. This is because of the presence of other limiting factors like climate, terrain relief and soils that make yield potentials in these soils lower.

There are features in Guatemala’s sugarcane zone regarding the relationship between altitude, climate, relief and soil and their relation with yield. The results are interesting when yield is stratified in ranges for the estimation of fertiliser doses as is currently made in mills, simultaneously with other factors associated with these yields.

### Crop response to N application

With regard to soil fertility, it has been found that, in the sugarcane region of Guatemala, the OM is a factor that explains responses of nitrogen applications (Table 2).

Data in Table 2 show that, in 94% of cases, an increase in tonnage is achieved (higher than 20%) when OM contents in soil are lower (OM <3.0%) whereas, in soils with higher OM contents (>5.0%), in 100% of the cases the increase is lower than 11%.

In soils with medium OM content, responses were variable, but in most of the cases they were lower than 20%. As was indicated before, lower values of OM are found in the coastal zone where high yield Mollisol and Entisol soils are located which are the areas with high response to nitrogen.

### Table 1—General and chemical features of Guatemala sugarcane region and cane yield according to four macro altitudinal strata.

<table>
<thead>
<tr>
<th>Altitudinal stratum</th>
<th>General features</th>
<th>Chemical features</th>
<th>TCH average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Annual average T°(°C)</td>
<td>Rainfall (mm)</td>
<td>Predominant soil</td>
</tr>
<tr>
<td>High (&gt; 300 masl)</td>
<td>23.6</td>
<td>3239</td>
<td>Andisol</td>
</tr>
<tr>
<td>Middle (100–300 masl)</td>
<td>26.7</td>
<td>2779</td>
<td>Andisol Inceptisol</td>
</tr>
<tr>
<td>Low (40–100 masl)</td>
<td>27.3</td>
<td>2134</td>
<td>Andisol Inceptisol</td>
</tr>
<tr>
<td>Coastal (&lt; 40 masl)</td>
<td>27.5</td>
<td>1631</td>
<td>Mollisol Entisol</td>
</tr>
</tbody>
</table>


### Table 2—Response probabilities to N according to Guatemala sugarcane soil OM content (Adapted from Perez, 2007).

<table>
<thead>
<tr>
<th>Predominant soil</th>
<th>OM category</th>
<th>Low response &lt; 11% TCH</th>
<th>Median response 11–20% TCH</th>
<th>High response &gt; 20% TCH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mollisol–Entisol</td>
<td>Low (&lt; 3.0%)</td>
<td>0</td>
<td>6</td>
<td>94</td>
</tr>
<tr>
<td>Andisol–Inceptisol</td>
<td>Medium (3.0–5.0%)</td>
<td>31</td>
<td>47</td>
<td>21</td>
</tr>
<tr>
<td>Andisol</td>
<td>High (&gt; 5.0%)</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
In Table 3, nitrogen dose recommendations for Guatemala sugarcane zone are presented, based on defined OM criteria and crop responses found in plant cane and ratoon cane in different experimental and validated tests carried out by sugar mills (Pérez, 2007; La Unión Mill, 2005).

Nitrogen recommendations for plant cane crop varies from 60 to 80 kg of N/ha whereas, in ratoon crops, recommendations are higher depending on OM in soil and yield potential of the sugarcane plantation.

In soils with lower OM content (<3.0%), it has been found that there is a need of 1.14 kg of N per tonne of produced cane (Nitrogen Cane Tonne Ratio: N:TC) whereas, in soils with medium and high OM contents, N:TC ratio is lower (1.0) (Perez, 2007). These two values from now on will be named Reference N:TC ratios.

N recommendations (kg/ha) for different OM categories in Table 3 indicate the fluctuation in nitrogen doses in less productive plots (doses lower range) to more productive plots (doses higher range).

Table 3—Nitrogen recommendations (N kg/ha) and reference N:TC ratio for volcanic ash derived soils in Guatemala. (Adapted from Perez, 2007).

<table>
<thead>
<tr>
<th>Predominant soil</th>
<th>OM category</th>
<th>Plant cane (N kg/ha)</th>
<th>Ratoon (N kg/ha)</th>
<th>Reference N:TC ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mollisol–Entisol Low</td>
<td>(&lt; 3.0%)</td>
<td>80</td>
<td>100–170</td>
<td>1.14</td>
</tr>
<tr>
<td>Andisol–Inceptisol Medium (3.0–5.0%)</td>
<td>60–80</td>
<td>90–140</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Andisol High (&gt; 5.0%)</td>
<td></td>
<td>60</td>
<td>80–110</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Nitrogen dose adjustment according to N:TC ratio

Nitrogen doses adjustment in current fertilisation programs involves a better way to optimise investment in chemical fertilisers used in sugar mills, avoiding overdose in lower response areas and adapting doses in areas that have higher probabilities to respond.

Given that nowadays all of the Guatemalan sugar mills use sugarcane plantation yield criteria and crop age to establish N doses to be used in defined fields, it was decided to review current N:TC ratios adding OM content as a decision criterion in recommendations.

This criterion is expected to result in N dose adjustments that will have greater economical impact on fertilisation programs mainly in ratoon crops given by the variability that exists in N:TC ratios for the same cane yield range (same yield group).

Current ratio variations will depend on range cane yield amplitude that is being used, and it would be wider variation in cases where only two categories exist (high and low yield).

Nitrogen dose adjustments will depend on crop cycle. In plant cane, adjustment has less impact, due to the fact that sugar mills currently fertilise according to the recommendations given in Table 3; however, a different situation applies in ratoon crops.

Table 4 shows a typical case of ratoon cane where the current fertilisation program is based exclusively on cane yield (TCH) with three different groups: low (< 90 TCH); intermediate (90–110 TCH) and high (>110 TCH) with applications of 100, 120 and 140 kg of N/ha respectively.

As a result, N:TC ratios vary from >1.12, 1.33 to 1.09 and < 1.26 for the three yield categories: low, intermediate and high, respectively.

Inside the three main groups of TCH, N:TC ratios increase as yield decreases, due to the fact that N dose remains constant. Variations in N:TC are greater as yield ranges are extended.
Table 4—Cane yield groups and intra-group variation of current relation N:TC ratios according to current N fertilisation.

<table>
<thead>
<tr>
<th>Cane yield (TCH)</th>
<th>Group</th>
<th>TCH intra-group</th>
<th>Current N doses (kg/ha)</th>
<th>Current relation N:TC ratios1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 90</td>
<td>80</td>
<td>100</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>85</td>
<td></td>
<td>1.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>89</td>
<td></td>
<td>1.12</td>
</tr>
<tr>
<td>90–110</td>
<td></td>
<td>90</td>
<td>120</td>
<td>1.33</td>
</tr>
<tr>
<td></td>
<td></td>
<td>95</td>
<td></td>
<td>1.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100</td>
<td></td>
<td>1.20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>105</td>
<td></td>
<td>1.14</td>
</tr>
<tr>
<td></td>
<td>&gt; 110</td>
<td>110</td>
<td></td>
<td>1.09</td>
</tr>
<tr>
<td></td>
<td></td>
<td>111</td>
<td></td>
<td>1.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td>115</td>
<td>140</td>
<td>1.21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>120</td>
<td></td>
<td>1.17</td>
</tr>
</tbody>
</table>

1Current relation N:TC ratios = Current N dose/TCH intra-group.

As mentioned, current fertilisation programs generally are based only on TCH categories. However, N dose adjustment is proposed according to N:TC ratio based on OM content applied in four categories. Table 5 shows an example of how to optimise N:TC ratio variability, introducing first a new approach consisting of an extra cane yield category into the current intermediate category and second by using as a reference OM contents of the soil. The reason why two new intermediate categories are proposed is because the average TCH of the Guatemala industry is in this range. Thus, as a result, the new intermediate category groups have more yield data, so any variation will have better impact on adjustments.

Table 5—Adjusted N doses by using Reference N:TC ratios and intra-group variation of N:TC ratios adding a new cane yield category.

<table>
<thead>
<tr>
<th>Cane yield (TCH)</th>
<th>1Adjusted N dose (kg/ha)</th>
<th>2Adjusted N:TC ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TCH Intra- group</td>
<td>Soils with OM &lt; 3.0%</td>
</tr>
<tr>
<td>Group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 90</td>
<td>80</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>85</td>
<td></td>
</tr>
<tr>
<td></td>
<td>89</td>
<td></td>
</tr>
<tr>
<td>90–100</td>
<td>90</td>
<td>114</td>
</tr>
<tr>
<td></td>
<td>95</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>101–110</td>
<td>101</td>
<td>126</td>
</tr>
<tr>
<td></td>
<td>105</td>
<td></td>
</tr>
<tr>
<td></td>
<td>110</td>
<td></td>
</tr>
<tr>
<td>&gt; 110</td>
<td>111</td>
<td>138</td>
</tr>
<tr>
<td></td>
<td>115</td>
<td></td>
</tr>
<tr>
<td></td>
<td>120</td>
<td></td>
</tr>
</tbody>
</table>

1Adjusted N dose = estimated from superior TCH in each Intra-group multiplied by respective reference N:CT ratio (1.14 and 1.00). 2Adjusted N:TC ratio = Adjusted N dose/TCH intra-group.

In Table 5, it is observed that splitting the intermediate original category (90–110 TCH) in two: from 90 to 100 and from 101 to 110 TCH and adjusting N dose with Reference N:TC ratios 1.14 and 1.0 for soils with OM < 3.0% and soils with OM > 3.0%, respectively, a better balance of N doses is achieved. It is also observed that, in soils with high OM content (> 3.0%), N recommendations are reduced significantly compared to the original recommendations shown as current N doses (kg/ha) in Table 4. Additionally, for soils with less than 3.0% OM, N recommendations are better distributed when four TCH classifications are considered.
Obviously better adjustments could be achieved by introducing more categories to fertilisation programs. N recommendations would be advisable to the parcel level (specific site recommendations). The above improvements can be obtained by taking into consideration that all Fertilisation Programs must be operative and functional based on real possibilities and that the programs have economic feasibility.

It is advisable that each Guatemalan sugar mill reviews its current fertilisation program and then makes the necessary recommended N dose adjustments. Afterwards, the recommended programs must be adjusted slightly according to particularities inherent to site and agronomical management. Finally, it is important to emphasise the need for review and supervision of applications in order to make them correctly, including calibration of fertiliser machines, the seasons, and methods of fertiliser application.

**N dose review as a function of fertiliser price variations**

N optimal economic doses (NOED) must relate to N price variations and current sugar prices. However, this NOED variation with given prices changes depending on crop N response. When N response is high, NOED variation is smaller than in lower responses. In Table 6, NOED adequacy from one year to another according to fertiliser and product price update for different N response in terms of OM in soils is presented.

**Table 6**—NOED variation from 2007 to 2008 according to N price variation.

<table>
<thead>
<tr>
<th>Soil OM (%)</th>
<th>Year</th>
<th>(^{1})Price relationship I/P</th>
<th>(^{2})NOED (kg/ha)</th>
<th>NOED reduction with new prices (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 5.0</td>
<td>2007</td>
<td>1.21</td>
<td>109</td>
<td>13.0</td>
</tr>
<tr>
<td></td>
<td>2008</td>
<td>1.93</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td>3.0–5.0</td>
<td>2007</td>
<td>1.21</td>
<td>126</td>
<td>11.0</td>
</tr>
<tr>
<td></td>
<td>2008</td>
<td>1.93</td>
<td>112</td>
<td></td>
</tr>
<tr>
<td>&lt; 3.0</td>
<td>2007</td>
<td>1.21</td>
<td>162</td>
<td>8.6</td>
</tr>
<tr>
<td></td>
<td>2008</td>
<td>1.93</td>
<td>148</td>
<td></td>
</tr>
</tbody>
</table>


\(^{1}\)Price relationship I/P = Price relationship of: US$ 1qq Urea/US$ 1 t of cane. \(^{2}\)NOED: Nitrogen optimal economic dose: Estimated from regression functions for soils with low, medium and high OM content.

When the price of a quintal (45.45 kg) of fertiliser increases from US$19 to $35 and in the presence of a relatively constant sugar price (in price per tonne of cane terms), NOED are reduced invariably. Nevertheless, NOED percentage reduction is lower in high N response soils (OM < 3.0%), 8% reduction compared with a 13% reduction necessary for soils with lower response (OM >5.0%).

**Alternatives to reduce dependence on chemical nitrogen fertilisers**

Options and practices that can be mentioned and used to reduce the crop’s nitrogen fertiliser need are: green manure, vinasse, filter mud, and biological nitrogen fixation.

**Green manure use**

Green manuring constitutes one of the most viable options to reduce sugarcane crop N use, and it is a practice that helps improve cane yield and sustainability. Introduction of a leguminous crop in a conventional sugarcane system brings a series of direct and indirect benefits on breaking sugarcane monoculture (Garside and Bell, 1999; Wiseman 2005).

*Crotalaria juncea* and *Canavalia ensiformis*, planted as green manures in sugarcane nurseries as a crop rotation, allow 100% of nitrogen fertilisation savings, with an expected increase of cane seed production. In Guatemala, in a Mollisol soil, four and 11% cane seed yield increases were obtained when *C. juncea* and *C. ensiformis* were rotated in relation to the control without
rotation (Cengicaña, 2009). In Australia, increases are reported of 20 and 30 percent of tonnage with soybean and peanut rotations in sugarcane plantation renewals. (Garside et al., 2001)

In Guatemala, under an superficial Andisol, it has been demonstrated that C. juncea monoculture could accumulate up to 235 kg of N/ha in its aerial bio-mass in only 65 days, while C. ensiformis N accumulation is slightly slower (175 kg of N/ha) (Pérez et al., 2008). On the other hand, it has been shown that C. ensiformis, intercropped between sugarcane rows in plant cane and ratoons, could be an option in high OM content soils such as superficial Andisols in the region (Table 7).

Table 7 shows that cane yield was not affected by the intercropping of any of the legumes as compared with the control, even when they were not chemically fertilised. Rather, it appears that cane yields were on average slightly higher (though not significant at P: 0.05) than the control at the end of four years, particularly with Canavalia.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Canavalia ensiformis + cane without N</td>
<td>82.8(a)</td>
<td>111.2(a)</td>
<td>95.0 (a)</td>
<td>108.7(a)</td>
<td>99.4 (a)</td>
</tr>
<tr>
<td>Crotalaria juncea + Cane without N</td>
<td>74.7(a)</td>
<td>109.3(a)</td>
<td>91.1 (a)</td>
<td>108.6(a)</td>
<td>95.9 (a)</td>
</tr>
<tr>
<td>Control (cane alone + N )</td>
<td>74.1(a)</td>
<td>103.7(a)</td>
<td>88.3 (a)</td>
<td>109.9(a)</td>
<td>94.0 (a)</td>
</tr>
</tbody>
</table>

In any column, means followed by a common letter are not significantly different (Tukey 0.05).

Green manures represent a great potential in sugarcane crop N savings. In the short term, it is recommended to initiate these practices in sugarcane nurseries, because their designated areas are without any use for three to four months. In the sugarcane crop of Guatemala, the potential of this technique is estimated to be the 5000 hectares which are designated for nurseries in a year. While leguminous management is becoming familiar and experience is achieved, the thought of its use will be possible in renewable areas where there is time pressure between harvest and planting a new plantation, and more research will be needed. Finally, the intercropping system will have to be focused in marginal areas where sugarcane growth is slower due to limiting climatic conditions, and in areas susceptible to erosion and pests and diseases.

Vinasse use

Vinasse is an industrial residue from the alcohol distillation process and basically it is made up of water, OM and mineral salts. It is being used in sugarcane crop fields because it increases yield, reduces fertiliser use and, generally, improves soil. (Pennati et al., 2005)

Possibilities of reducing N doses used in sugarcane crop fields with vinasse could be important. Table 8 presents an average of TCH observed in four years with different and successive vinasse applications under different N doses in a Guatemalan sugarcane Andisol.

<table>
<thead>
<tr>
<th>Vinasse (m³/ha)</th>
<th>N (kg/ha)</th>
<th>0</th>
<th>50</th>
<th>100</th>
<th>³Average effect of vinasse</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td>103.8 (b)</td>
<td>110.3 (ab)</td>
<td>111.1 (ab)</td>
<td>108.4 (b)</td>
</tr>
<tr>
<td>30</td>
<td>114.2 (ab)</td>
<td>116.3 (a)</td>
<td>112.1 (ab)</td>
<td>114.2 (a)</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>115.4 (a)</td>
<td>117.3 (a)</td>
<td>120.6 (a)</td>
<td>117.8 (a)</td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>119.9 (a)</td>
<td>115.1 (a)</td>
<td>119.1 (a)</td>
<td>118.0 (a)</td>
<td></td>
</tr>
</tbody>
</table>

³The means of this column are interpreted separately from 0, 50 and 100 N (kg/ha)

Means followed by a common letter are not significantly different (Tukey 0.05)
In Table 8, it is observed that, in absence of vinasse, tonnage increased with variable N doses from 103.8 to 111.1 TCH with 0 and 100 kg of N/ha respectively. However, in presence of any vinasse level applied, the effect of nitrogen is lower.

Although the nitrogen content of the vinasse is low, it is possible that the addition of this energy-rich material in soils with high carbon content such as Andisols of Guatemala has a ‘priming’ effect, thus increasing the availability of nitrogen to the crop.

On the other hand, trying to explain why there is a positive effect due to increased vinasse applications, there is an indication that the effluent is contributing to the nitrogen crop needs and it would be correcting at the same time other limiting nutrients in these soils.

Due to the fact of existing soil diversity in Guatemala, it is recommended to have wider evaluations and validate promising treatments at semi-commercial levels in order to reduce N doses where vinasse is applied. This approach will help growers to have information in the short term for their decision-making process over N optimisation and vinasse use.

**Nitrogen biological fixation**

N biological fixation (NBF) in sugarcane crops is a recent and interesting subject due to the great potential depicted by crop nutrition and nitrogen economy. NBF in sugarcane is supported by the discovery of endophytic diazotrophic bacteria, being *Gluconacetobacter diazotrophicus*, the most studied species related to the process.

The most recent progress refers to the end of the *Gluconacetobacter diazotrophicus* genome sequence (Guedes et al. 2008). In the near future, this advance will allow information about bacterial genes interaction with sugarcane genotypes. When the gene decoding process is finished, it will be possible to increase NBF efficiency using Biotechnology (Segundo Urquiaga, personal communication).

In Guatemala, *Gluconacetobacter* sp has been isolated in most sugarcane cultivars, and it has been found that some cultivars like PGM89-968, at an experimental level, is capable of obtaining 50% or more N via NBF (Pérez et al. 2005)

**Conclusions**

The use of reference N:TC ratios of 1.14 and 1.0 for soils with OM<3.0% and soils with OM>3.0% respectively as a decision criterion in nitrogen recommendations permit the optimisation of the investment in chemical nitrogen fertiliser in the sugarcane crop in Guatemala. On the other hand, N doses must be adjusted to fertiliser and sugar prices according to crop N response.

To reduce dependence on nitrogen fertilisers, there are practices that must be taken into account and be optimiced in the short term.

These practices consist of usage of species of green manure adapted to the intercropping system, the use of co-products and, in the mid and long term, there is potential for nitrogen biological fixation in the sugarcane crop.

**Acknowledgements**

The authors wish to thank Jose del Cid and Fernando Hernandez, technicians of Agronomy Program and Hector Orozco, head of Varieties Program of Cengicaña, for the review and comments to the present document.

**REFERENCES**


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**STRATEGIES POUR UNE UTILISATION OPTIMALE DES ENGRAIS AZOTES EN CULTURE DE CANNE A SUCRE AU GUATEMALA**

Par

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MOTS CLES: Azote, Optimisation, Jachère Verte,
Fixation Biologique de N.

Résumé

L’OBJET de ce travail est de présenter des éléments pratiques qui aideront les producteurs de canne à sucre à optimiser leur investissement en matière d’engrais azotés pour la culture de la canne à sucre au Guatemala. Cette étude est importante à cause de l’augmentation générale du prix des engrais et plus particulièrement celui de l’engrais azoté. Les critères ont basés sur la connaissance de la réponse de la culture à la fertilisation azotée dans la région après 14 années de recherche sur le
La respuesta a la azote es función del rendimiento de cana, de la fertilidad del suelo, de la edad y del ciclo de la cultura, así como de otras variables en relación con las prácticas agronómicas y el suelo. Ainsi, el nivel de fertilización azotada en uso en los programas de fertilización de las industrias sucrieras puede ser ajustado en comparación con la cantidad de azote en kg por tonelada de cana (N:TC), con tasas de referencia recomendadas para diferentes tipos de suelo según su contenido en materia orgánica (OM) y otras factores. Paralelamente, las cantidades de azote deben ser ajustadas en relación con el precio de los fertilizantes y de la cana para diferentes grupos. En alternativa a reducir la dependencia a los fertilizantes azotados, existen prácticas que deben ser tomadas en cuenta y optimizadas a corto plazo. Estas prácticas incluyen el uso de fertilizantes de cultivo intercalado, el uso de co-productos y, a mediano y largo plazo, el potencial de la fijación biológica de azote en el cultivo de cana a azúcar.
LUMAX®: AN ALTERNATIVE TO ATRAZINE FOR PRE- AND POST-EMERGENCE CONTROL OF WEEDS IN SUGARCANE

By

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KEYWORDS: Mesotrione, Terbuthylazine, S-Metolachlor.

Abstract

ATRAZINE has successfully been used for more than 40 years in various tank-mixes for both pre- and post-emergence control of weeds in sugarcane. However, the product is banned in the EU for environmental reasons. Lumax, consisting of three active ingredients namely mesotrione (0.0375 kg a.i./L), terbutylazine (0.125 kg a.i./L) and s-metolachlor (0.375 kg a.i./L), has been evaluated as a substitute for atrazine in Mauritius in ten field trials in both plant and ratoon sugarcane. Lumax at rates varying between 3.5 and 5.0 L/ha proved effective on a wide spectrum of broad-leaved weeds and some grasses, including *Digitaria horizontalis*. In general, Lumax was superior to the standard s-metolachlor + atrazine and comparable to the tank-mixes tebuthiuron + atrazine and oxyfluorfen + diuron. In post-emergence of weeds, although Lumax tank-mixed with 2,4-D amine salt showed a better control of weeds than atrazine tank-mixed with s-metolachlor + 2,4-D amine salt, it was slightly inferior to the other standards containing hexazinone or tebuthiuron. In all situations, Lumax provided a residual activity varying between 10 and 12 weeks and showed no phytotoxicity on the various sugarcane varieties tested. Lumax has been recommended as an alternative to atrazine at rates varying between 4.0 and 5.0 L/ha.

Introduction

Traditionally, weed control in sugarcane in Mauritius has been achieved by application of at least two herbicide treatments from planting or harvest up to complete canopy closure (MSIRI, 2004). While the first application consists solely of pre-emergence, subsequent applications also include a post-emergence herbicide such as 2,4-D amine salt in the tank-mixes. Atrazine has been one of the most-used pre-emergence herbicides during the last 50 years; it is normally tank-mixed with selective grass herbicides to broaden the spectrum of control and, together with a post-emergence herbicide, also provides early post-emergence control of weeds. The extensive use of atrazine is also associated with its broad tolerance by sugarcane varieties as compared to diuron which is restricted to tolerant ones (Mc Intyre and Barbe, 1995).

Although atrazine does not represent any risk of contamination of underground waters as reported elsewhere (MSIRI/ACIAR, 2001) and has no weed resistance being reported yet in Mauritius, there has been growing pressure to seek alternatives to it and several of its tank-mix partners which are no longer authorised in the EU, where the main importing countries of Mauritian sugar are found.

Lumax® consists of mesotrione, terbuthylazine and s-metolachlor. Mesotrione is a member of the trikete family and is a selective herbicide used for pre- and post-emergence control of broad-leaved and some grass weeds in field corn (Armel et al., 2001; Mitchell et al., 2001). The formulation of Lumax tested in this study contained 37.5 g mesotrione, 375 g s-metolachlor and 125 g terbuthylazine per litre of product. At rates varying between 3 to 4 L/ha, Lumax has been reported to provide satisfactory control in both pre- and early post-emergence of weeds in maize
(Rapparini and Fabbi, 2005). The objective of this study was to evaluate the efficacy of Lumax in pre- and early post-emergence of weeds in sugarcane and to assess its potential as an alternative to atrazine.

**Materials and methods**

Ten trials were conducted in both plant and ratoon sugarcane to evaluate the efficacy of Lumax in pre- and early post-emergence of weeds. The first four trials (Trials 1 – 4) involved pre-emergence control of weeds in plant cane where Lumax at 3.5, 4.0, 4.5 and 5.0 L/ha was compared to three standards, namely, oxyfluorfen + diuron (0.5 + 2.0 kg a.i./ha), tebuthiuron + atrazine (1.6 + 2.4 kg a.i./ha) and s-metolachlor + atrazine (1.4 + 2.4 kg a.i./ha), and to an untreated control. The same treatments were also assessed in ratoon cane in two other trials (Trials 5 and 6). The remaining trials (Trials 7 – 10) involved post-emergence control of weeds in plant cane (Trials 7 and 8) and in ratoon cane (Trials 9 and 10). For the post-emergence trials, the four rates of Lumax were tank-mixed with 2,4-D amine salt at 3.0 L/ha and were compared to three standards, namely, hexazinone + atrazine + 2,4-D amine salt (0.6 + 2.4 + 2.2 kg a.i./a.e./ha), tebuthiuron + atrazine + 2,4-D amine salt (1.3 + 2.4 + 2.2 kg a.i./a.e./ha) and s-metolachlor + atrazine + 2,4-D amine salt (1.4 + 2.4 + 2.2 kg a.i./a.e./ha). A non-ionic adjuvant @ 0.025% v/v was added to all post-emergence treatments. The characteristics and details of all trial sites are given in Table 1.

**Table 1**—Characteristics and details of trial sites.

<table>
<thead>
<tr>
<th>Trial no.</th>
<th>Site</th>
<th>Soil group *</th>
<th>Mean annual rainfall (mm)</th>
<th>Altitude (m)</th>
<th>Date of planting/harvest</th>
<th>Cane variety</th>
<th>Date of spraying</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bel Air</td>
<td>Low Humic Latosol</td>
<td>1775</td>
<td>95</td>
<td>28.04.05</td>
<td>R 573</td>
<td>03.05.05</td>
</tr>
<tr>
<td>2</td>
<td>Belle Mare</td>
<td>Lithosol</td>
<td>1300</td>
<td>30</td>
<td>21.03.06</td>
<td>R 570</td>
<td>28.03.06</td>
</tr>
<tr>
<td>3</td>
<td>Rose Belle</td>
<td>Latosolic Brown Forest</td>
<td>3575</td>
<td>345</td>
<td>25.07.06</td>
<td>M 1394/86</td>
<td>01.08.06</td>
</tr>
<tr>
<td>4</td>
<td>FUEL</td>
<td>Low Humic Latosol</td>
<td>2450</td>
<td>170</td>
<td>12.09.06</td>
<td>R 579</td>
<td>02.10.06</td>
</tr>
<tr>
<td>5</td>
<td>Riche en Eau</td>
<td>Humic Ferruginous Latosol</td>
<td>2500</td>
<td>150</td>
<td>25.10.06</td>
<td>R 570</td>
<td>06.11.06</td>
</tr>
<tr>
<td>6</td>
<td>FUEL</td>
<td>Humic Latosol</td>
<td>2875</td>
<td>255</td>
<td>06.04.07</td>
<td>M 1246/84</td>
<td>13.04.07</td>
</tr>
<tr>
<td>7</td>
<td>Belle Mare</td>
<td>Lithosol</td>
<td>1300</td>
<td>30</td>
<td>21.03.06</td>
<td>R 570</td>
<td>17.05.06</td>
</tr>
<tr>
<td>8</td>
<td>Rose Belle</td>
<td>Latosolic Brown Forest</td>
<td>3575</td>
<td>345</td>
<td>25.07.06</td>
<td>M 1394/86</td>
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</tr>
<tr>
<td>9</td>
<td>Riche en Eau</td>
<td>Latosolic Brown Forest</td>
<td>2600</td>
<td>140</td>
<td>15.10.06</td>
<td>M 1400/86</td>
<td>14.11.06</td>
</tr>
<tr>
<td>10</td>
<td>Combo</td>
<td>Humic Ferruginous Latosol</td>
<td>3200</td>
<td>410</td>
<td>16.04.07</td>
<td>R 579</td>
<td>04.06.07</td>
</tr>
</tbody>
</table>

* According to Parish and Feillafé (1965).

Spraying was carried out using hand-operated knapsack sprayers, delivering 350 L/ha at 300 kPa. The statistical design was a completely randomised block with three replicates; each plot consisted of four 1.6-m rows 10 m long (plot size of 64 m²).

For pre-emergence trials, data collection comprised visual observations at four and eight weeks after spraying (WAS) to record weed species appearing in the various treatments, followed by two weed surveys between 12 and 16 WAS using the ‘Frequency Abundance Method’ (Rochecouste, 1967). The level of control by each treatment on predominating weeds at each site was also highlighted. Regular visual observations on possible phytotoxicity on sugarcane were also made, followed by cane measurements in the plant cane at 12 WAS to determine any effect of Lumax on cane growth and tillering.

For post-emergence trials, a weed survey was carried out prior to spraying about eight weeks after planting or harvest in each individual plot to identify and quantify all weeds present. Following spraying, a second weed survey was carried out as from 4 WAS to assess the post-
emergence efficacy of each treatment; the percent weed kill was calculated by dividing the difference in weed infestation using the ‘Frequency Abundance Method’ between the two surveys by the initial infestation. The second survey made around 12 WAS was focused on assessing the length of residual activity of Lumax treatments with respect to the standards.

Results

Efficacy of Lumax in pre-emergence of weeds

In plant cane

At all four sites, the predominant broad-leaved weeds included *Ageratum conyzoides*, *Bothriospermum zelanicum*, *Chamaesyce hirta*, *Phyllanthus* sp., *Oxalis* spp., *Solanum nigrum* and *Youngia japonica*. *Digitaria horizontalis*, *Paspalum urvillei* and *Panicum subalbidum* were the main grass species in the untreated plots in Trials 2, 3 and 4 respectively. *Cyperus rotundus* was present in Trials 2 and 4 whereas *Kyllinga bulbosa* and *K. erecta* were recorded in Trial 3.

Observations made at 4 WAS revealed that the Lumax treatments were almost similar in efficacy to the standards and no difference among the four rates was apparent. At 8 WAS, the level of control obtained by the Lumax treatments were either similar or slightly inferior to the two standards, oxyfluorfen+diuron and tebuthiuron+atrazine; Lumax showed some superiority over the third standard, s-metolachlor + atrazine, due to its better efficacy on some broad-leaved weeds (Table 2).

The weed surveys made between 12 and 16 WAS revealed that the efficacy of Lumax, particularly at the two higher rates, was comparable to the standard oxyfluorfen + diuron and slightly inferior to tebuthiuron+atrazine (Figure 1). Irrespective of sites, control with Lumax was superior to s-metolachlor+atrazine; this indicates the contribution of mesotrione in the new product. Although the good performance of Lumax is explained by its efficacy on broad-leaved weeds which were predominant at those sites (Table 2), some weaknesses were observed on grass species such as *P. subalbidum*. For *D. horizontalis*, a good level of control was obtained with the two higher rates. Comparing the four rates of Lumax between 12 and 17 WAS showed that the highest rate of 5.0 L/ha had a slightly longer residual activity. The relatively better control obtained by Lumax at FUEL (Trial 4) may be explained by a longer residual activity associated with the dry conditions which prevailed throughout the duration of the trial at that site. Cane measurements made at all sites showed no difference in growth and tillering among the treatments; this confirms that this new herbicide is not phytotoxic to the sugarcane varieties tested.

| Table 2—Relative efficacy of Lumax for the pre-emergence control of some common weeds in plant cane (Trials 1–4). |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
| Lumax (L/ha) | oxyf+diuron (0.5+2.0 kg a.i./ha) | teb+atraz (1.6+2.0 kg a.i./ha) | s-meto + atraz (1.5+2.0 kg a.i./ha) |
| 3.5 | 4.0 | 4.5 | 5.0 |
| A. conyzoides | +++ | +++ | +++ | ++++ | +++ | ++++ | +++ | + |
| B. zelanicum | +++ | +++ | ++++ | ++++ | +++ | ++++ | +++ | + |
| C. rotundus | + | + | + | + | + | + | + | + |
| D. horizontalis | ++ | ++ | +++ | +++ | +++ | +++ | ++ | + |
| K. bulbosa | + | + | + | + | + | + | + | + |
| K. erecta | +++ | +++ | ++++ | ++++ | ++++ | ++++ | ++++ | ++++ |
| O. comicutata | +++ | +++ | ++++ | ++++ | ++++ | ++++ | ++++ | ++ |
| P. urvillei | ++ | ++ | ++ | ++ | ++ | ++ | ++ | + |
| P. subalbidum | ++ | ++ | ++ | ++ | ++ | ++ | ++ | + |
| S. nigrum | +++ | ++++ | ++++ | ++++ | ++++ | ++++ | ++++ | +++ | + |

+ Poor ++ Fair +++ Good ++++ very good
oxyf+diuron= oxyfluorfen + diuron, teb+atraz= tebuthiuron + atrazine; s-meto+atraz = s-metolachlor + atrazine
In ratoon cane

The two trials carried out in ratoon cane confirmed the results from the plant cane trials. The two higher rates of Lumax were again more effective than the lower rates and were comparable to the three standards (Figure 2). The survey carried out at 17 WAS in Trial 6 showed that the residual activity of Lumax was shorter than that of oxyfluorfen + diuron under more humid conditions. It was found to provide a similar level of control to the standards of *D. horizontalis* at the highest rate tested.

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### Fig. 1—Pre-emergence control of weeds by Lumax in plant cane and expressed as % of weed infestation in the untreated control.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>3.5 L/ha</th>
<th>4 L/ha</th>
<th>4.5 L/ha</th>
<th>5 L/ha</th>
<th>0.5 + 2.0 kg a.i./ha</th>
<th>1.6 + 2.4 kg a.i./ha</th>
<th>1.4 + 2.4 kg a.i./ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lumax</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxyfluorfen + diuron</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tebuthiuron + atrazine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-metolachlor + atrazine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

### Fig. 2—Pre-emergence control of weeds by Lumax in ratoon cane and expressed as percent of weed infestation in the untreated control.
Efficacy of Lumax in early post-emergence of weeds

In plant cane

The predominating weeds before spraying in Trial 7 consisted of *Cleome viscosa*, *C. rotundus*, *D. horizontalis*, *C. hirta*, *Ipomoea obscura*, *Phyllanthus sp.* and *Vernonia cinerea*.

Near complete eradication of most weeds except *D. horizontalis* was obtained 2 WAS with the lowest rates of Lumax. *V. cinerea* was only partly scorched; efficacy on this weed species improved with increase in dosage and, at the highest rate, was comparable to the two standards hexazinone + atrazine + 2,4-D amine salt and tebuthiuron + atrazine + 2,4-D amine salt.

The third standard was slightly inferior to Lumax due to a less effective control of *C. hirta*. The percent weed kill determined as from 4 WAS showed the standard hexazinone + atrazine + 2,4-D amine salt to be the best treatment, closely followed by the two other standards (Figure 3).

Control by Lumax was on the whole very satisfactory with more than 70% weed kill in Trial 7 (Figure 3). No significant difference between the four rates of Lumax was apparent.

Predominating weeds at Rose Belle (Trial 8) consisted of *A. conyzoides*, *Crassocephalum rubens*, *D. horizontalis*, *D. radicosa*, *Eleusine indica*, *Kyllinga bulbosa*, *Lobellia cliffortiana*, *O. debilis*, *O. corniculata*, *Paspalum urvillei*, *Solanum nigrum* and *Youngia japonica*.

A good knockdown of broad-leaved weeds was obtained 2 WAS with Lumax, irrespective of rate, and was comparable to the standard s-metolachlor + atrazine + 2,4-D amine salt (Figure 3). The two other standards were superior due to a more effective control of grasses.

In both trials, the tank-mixes with Lumax were shown to be safe to cane varieties R 570 and M 1394/86. Cane variety R 570 which is known to be very susceptible to some post-emergence herbicide treatments showed some phytotoxicity towards the standard tank-mix hexazinone+atrazine+2,4-D amine salt (Figure 4).

Fig. 4—Effect of post-emergence application of Lumax on plant cane. Error bars show standard error of means.

The residual activity of the Lumax treatment, following the knock-down of weeds present at spraying, was found to increase with higher dosage; the highest rate of Lumax was better or as good as the best standard in the two trials.

**In ratoon cane**

Broad-leaved weeds were predominant in Trial 9 and *P. subalbidum* was the only grass present. Five WAS, Lumax, irrespective of rate in the tank-mixes, had completely eradicated *Solanum nigrum*. Species of the Euphorbiaceae family, namely *Phyllanthus* sp., *C. hirta* and *C. prostrata* were partly defoliated and had stunted growth whereas *P. subalbidum* was unaffected. Lumax treatments were in general comparable to the s-metolachlor tank-mix but inferior to the two other standards (Figure 5).

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![Graph](image-url)

**Fig. 5**—Post-emergence control of weeds by Lumax in ratoon cane.
With the predominance of broad-leaved weeds in Trial 10, very good control was obtained with Lumax, irrespective of dosage. Only two species were not totally controlled, namely Drymaria cordata (severely scorched) and Clidemia hirta (showing partial chlorosis and scorching). The best treatment was the standard tebuthiuron tank-mix with near eradication of most weeds except C. hirta. The two other standards were comparable to Lumax treatments (Figure 5).

Visual observations made throughout the duration of trials revealed all Lumax treatments to be safe to sugarcane varieties M 1400/86 and R 579. The latter, classified as a moderately susceptible variety to some post-emergence herbicide treatments, showed some phytotoxicity to the tank-mix containing hexazinone.

Discussion

Pre-emergence potential of Lumax

In general, the level of control obtained with Lumax was found to improve with increasing rates. The three higher rates tested were often superior to the standard s-metolachlor + atrazine; the superiority of Lumax over s-metolachlor+atrazine has also been demonstrated by Palacio-Vazquez et al. (2004). Compared to the two other standards of oxyfluorfen + diuron and tebuthiuron + atrazine, Lumax showed some potential under drier conditions at FUEL, where it provided the best pre-emergence control. However, tebuthiuron + atrazine proved to be more effective than Lumax at all remaining sites. Lumax was comparable to oxyfluorfen + diuron at sites where broad-leaved weeds predominated and inferior to the latter and tebuthiuron + atrazine on some grasses except *D. horizontalis*. The efficacy of Lumax on the latter weed complements observations reported by Armel et al. (2001) where *D. sanguinalis* is listed among weeds controlled by mesotrione. Despite its relative efficacy on *Kyllinga erecta*, Lumax was generally ineffective on sedges, including *Cyperus rotundus*. The latter concurs with results reported by Earl et al. (2004) showing mesotrione to be less effective than MSMA and halosulfuron on *C. esculentus*. As the three standards are also ineffective on *C. rotundus* and some other sedges, the potential of Lumax as a pre-emergence treatment for general weed control cannot be underestimated.

The trials have also revealed that Lumax has a relatively long residual activity up to 16 WAS. There seemed to be no significant difference among the three higher rates which implies that the highest rate of 5.0 L/ha is not justified and the optimum rates would be between 4.0 and 4.5 L/ha.

Post-emergence potential of Lumax

Lumax tank-mixed with 2,4-D amine salt proved particularly effective on broad-leaved weeds and was found to be as good as the standard s-metolachlor tank-mix and slightly inferior to the two other standards due to a less effective control of grasses.

No significant difference between the four rates of Lumax was observed. However, as the residual activity following the initial kill is also an important factor in weed management, the lowest rate of Lumax proved less effective. The highest rate of Lumax did not improve significantly the residual activity over the mid-rate.

The tank-mix Lumax + 2,4-D amine salt was well tolerated by the sugarcane varieties tested. As two of the trials consisted of susceptible varieties (R 570 and R 579), this implies that Lumax can be safely applied in post-emergence of both plant and ratoon sugarcane.

Conclusion

Based on results obtained in the ten trials, Lumax has a potential for use in pre- or post emergence of broad-leaved weeds and some grasses such as *D. horizontalis* in both plant and ratoon sugarcane. Lumax is a good alternative to conventional treatments such as s-metolachlor or acetochlor + atrazine which have been used since the early 1980s. Lumax has been recommended as an alternative to atrazine at rates varying between 4.0 and 4.5 L/ha in post-emergence of weeds, and the same rates of Lumax may be tank-mixed with 2,4-D amine salt @ 3.0 L/ha.
REFERENCES

LUMAX® : UNE ALTERNATIVE À L'ATRAZINE POUR LA MAITRISE EN PRÈ ET POST EMERGENCE DES MAUVAISES HERBES EN CANNE À SUCRE

Par
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MOTS-CLÉS: Mesotrione,
Terbuthylazine, S-Metolachlor.

Résumé
L'ATRAZINE a été employée avec succès pendant plus de 40 ans dans différentes mélanges afin de maîtriser l’enherbement en canne à sucre, à la fois en pré et post émergence. Cependant le produit n’est plus homologué en Europe pour des raisons environnementales. Le Lumax, un mélange comprenant 3 molécules actives, la mesotrione (0.0375 kilogramme m.a./L), la terbutylazine (0.125 kilogramme m.a./L) et le s-metolachlor (0.375 kilogramme m.a./L), a été évalué comme produit de remplacement de l'atrazine à l’île Maurice, dans dix essais au champ à la fois en canne
plantée et en repousses. Du Lumax, à des doses variant entre 3.5 et 5.0 L/ha s’est montré efficace sur une vaste gamme de mauvaises herbes à larges feuilles et de quelques graminées, comprenant Digitaria horizontalis. Généralement Lumax s’est montré supérieur au mélange standard s-metolachlor + atrazine et comparable au mélange de tebuthiuron + atrazine et de oxyfluorfen + diuron. En post émergence des mauvaises herbes, bien que le Lumax mélangé à un sel de 2,4-D amine ait provoqué une meilleure maîtrise des mauvaises herbes que l’atrazine mélangée à du s-metolachlor + un sel de 2,4-D amine, ce premier mélange à base de Lumax fut légèrement inférieur aux autres produits standards contenant de l’hexazinone ou du tebuthiuron. Dans toutes les situations, le Lumax a présenté une activité résiduelle variant entre 10 et 12 semaines et n’a montré aucune phytotoxicité sur les variétés de canne à sucre testées. Lumax a été recommandé comme alternative à l’atrazine à des doses variant entre 4.0 et 5.0 L/ha.

LUMAX®: ALTERNATIVA A LA ATRAZINA PARA CONTROL EN PRE Y POST-EMERGENCIA DE MALEZAS EN CAÑA DE AZÚCAR

Por

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PALABRAS CLAVE: Mesotrione, Terbutilazina, S-Metolacloro.

Resumen

La atrazina ha sido utilizada con éxito por más de 40 años en variadas mezclas de tanque para control, tanto en pre y post-emergencia, de malezas en caña de azúcar. Sin embargo, el producto está prohibido en la UE por razones ambientales. Lumax, consistente en tres ingredientes activos llamados mesotrione (0.0375 kg i.a./L), terbutilazina (0.125 kg i.a./L) y s-metolacloro (0.375 kg i.a./L), ha sido evaluado como un substituto de la atrazina en Mauricio, en diez ensayos de campo tanto en caña de azúcar planta como soca. Lumax, en dosis que varían entre 3,5 y 5 L/ha, probó su efectividad en un amplio espectro de malezas de hoja ancha y algunos pastos, incluyendo Digitaria horizontalis. En general, Lumax fue superior a la mezcla estándar s-metolacloro + atrazina y comparable a las mezclas de tanque tebuthiuron + atrazina y oxyfluorfen + diuron. En post-emergencia de malezas, a pesar que la mezcla de tanque de Lumax con 2,4-D sal amina mostró un mejor control de malezas que la mezcla de tanque de atrazina con s-metolacloro + 2,4-D sal amina, fue levemente inferior a otras estándares que contienen hexazinone o tebuthiuron. En todas las situaciones, Lumax proveyó una actividad residual que varió entre 10 y 12 semanas y no evidenció fitotoxicidad en las diferentes variedades de caña de azúcar evaluadas. Lumax ha sido recomendado como una alternativa a la atrazina en dosis que varían entre 4 y 5 L/ha.
INTERACTIONS BETWEEN SEED DEPTH, THICKNESS OF TRASH BLANKET AND HERBICIDE TREATMENTS ON EMERGENCE OF VINE WEEDS IN SUGARCANE

By

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KEYWORDS: Ipomoea spp, Sulfentrazone, Diclosulam, Pre-Emergence Control.

Abstract

Vine weeds are appearing more frequently in sugarcane fields, particularly with the increasing adoption of green cane trash blanketing (GCTB). Current control measures are not effectively providing adequate control of these weeds. A project to develop strategies for managing vine weeds has been initiated and included three trials studying the factors influencing emergence of three Ipomoea species sown in trays. In the first trial, seeds of I. triloba and I. obscura were found to emerge at depths beyond 8 cm while germination of I. nil was reduced at seed depths greater than 4 cm. In the second trial, emergence of the three vine species was found to be unaffected by a trash layer of 5 cm whereas a significant reduction was observed as trash thickness was increased to 10 cm. An interaction between depth of the vine seed and thickness of trash layer was also noted; i.e. emergence of seeds at depths between 2 and 4 cm was reduced by more than 75% when covered by a trash layer of 10 cm. In the third trial, six pre-emergence herbicide treatments namely atrazine, atrazine + hexazinone, sulfentrazone, amicarbazone, trifloxysulfuron + ametryn, and diclosulam were tested for their efficacy against I. triloba sown at soil depths of 2, 6 and 10 cm. At 6 weeks after spraying (WAS), irrespective of seed depth, all herbicide treatments provided satisfactory control. The interaction between herbicide treatment and seed depth was significant at 12 WAS; irrespective of sowing depths, only sulfentrazone provided less than 5% germination over a period of 18 WAS. These results indicate that both thickness of the trash layer and choice of the herbicide treatment should be taken into consideration in the development of strategies to control vines in sugarcane under GCTB.

Introduction

Vine weed infestations are increasingly reported in sugarcane fields. Unlike other broad-leaved weeds, grasses and sedges normally present in sugarcane, vines have the ability to develop late in the season and spread long distances both horizontally and vertically, making control difficult. Vine infestations are often associated with green cane trash blanketing (GCTB) in both mechanised and manually harvested fields. The development of vine weeds is becoming a serious drawback to the adoption of GCTB, which is an economically and ecologically sustainable system in sugarcane (Seeruttun et al., 1992; Morandini et al., 2005).

The presence of vines in sugarcane is not new; studies date back to 1954 when Thakar and Singh (1954) reported that Ipomoea hederacea infestations caused losses of 20–25% in sugarcane in the Pusa area of Bihar by twining around clumps, bending the cane, damaging tops, causing stalks to remain undeveloped, and interfering with the harvest. In Australia, the problem emerged in the 1980s following the adoption of mechanised harvest in green cane (Calcino, 1986). Studies conducted in Brazil have shown that a trash cover of up to 20 t/ha did not totally prevent the emergence of Ipomoea spp. (Azania et al., 2002; Manechini et al., 2005). Ipomoea coccinea has
been reported as the most common and troublesome broad-leaved weed in Louisiana sugarcane fields (Jones, 2006); its competition with the crop can reduce yield as much as 30% over a season (Millhollon, 1988).

In Mauritius, *Paederia foetida* and *Passiflora suberosa* have always been found as localised infestations in sugarcane fields; these perennial species are effectively controlled by the recommended post-emergence herbicide tank-mixes (Seeruttun *et al.*, 2005). Several new and more invasive vine species have been observed in recent years; these are partly attributed to changes in some cultural practices including trash management (Ismael *et al.*, 2008). The new species which have been favoured by the more conducive conditions include *Ipomoea triloba*, *I. nil*, *I. hederifolia* and *I. obscura*. These vines are annuals and reproduce exclusively by large amounts of large seeds. *I. nil* and *I. triloba* are the most commonly found species and occur mainly in the humid and subhumid regions of the island. Earlier, it was thought that the rapid expansion of these two vines was due to the non-use of a pre-emergence herbicide treatment under GCTB conditions. However, it is observed that even in cases where pre-emergence herbicide treatments are applied several weeks after harvest when the trash has decayed, the vines are still ineffectively controlled. As several of the currently used pre-emergence herbicides are known to be effective on vines, the poor control remains unexplained. Furthermore, the use of post-emergence herbicides for the control of vines is not very practical as several flushes can emerge and application in well-developed or tall cane is not easy. This study has been initiated to investigate the individual and combined effects of seed depth, thickness of trash cover and some pre-emergence herbicide treatments on the germination and emergence of *Ipomoea* spp. in sugarcane with the final aim of developing appropriate management strategies.

**Materials and methods**

Three trials were established in fibreglass trays in 2008 at the Réduit Experimental Station of the Mauritius Sugar Industry Research Institute. *Ipomoea nil*, *I. obscura* and *I. triloba* were included in the first two trials whereas only *I. triloba* was involved in the third trial. The seeds of *I. nil* and *I. triloba* were obtained from vine plants grown on the station in 2007 whereas seeds of *I. obscura* were collected in a locality 10 km away where the agro-climatic conditions were similar to those prevailing at Réduit. To ensure a homogeneous germination, all seeds used were scarified with 98% sulfuric acid (Suwakhetnikom and Julakasewee, 2004). The fibreglass trays, which had holes pierced at the bottom to allow drainage of excess water after irrigation, were filled with soil collected from the same experimental station. The soil used is equivalent to an Oxisol, containing some 80% clay and 4.7% organic matter (Parish and Feillafé, 1965; Soil Survey Staff, 1999).

**Trial I—Vine species × sowing depths**

Trial I was established on 3 March 2008 and each tray (0.60 m × 0.30 m × 0.16 m) was partitioned into five compartments with metal sheets. Each compartment represented the experimental unit where 10 vine seeds were buried at depths of 0, 2, 4, 8 and 12 cm.

Each vine species was sown in a separate fibreglass tray. Each treatment was replicated four times in a split-plot design with vine species as the main plot and sowing depths as the sub-plot. The trays were placed in the open air and irrigated when required. Germination counts were carried out every 3 days after sowing over three weeks, during which the mean minimum and maximum temperature was 20°C and 27°C respectively. The rainfall recorded over the three weeks of experimentation was 154 mm. At the end of the trial, the seedlings of each vine species and at varying sowing depths were cautiously uprooted to measure the length of the hypocotyl.

**Trial II—Vine species × trash layer × sowing depths**

Trial II was set up on 28 March and the trays (0.90 m × 0.45 m × 0.25 m) were placed outdoor in a split-split plot design with vine species as the main plots, trash layers as the sub-plots and sowing depths as the sub-sub-plots. Each tray was divided into two compartments along the
length with iron sheets and each compartment was further sub-divided into five equal sections in which the same sowing depths as tested in Trial I were randomised. Two such trays represented the main plot where 10 seeds of I. nil, I. obscura and I. triloba were planted at the different depths. Three of the four compartments were afterwards covered with 5, 10 and 15 cm layers of dry trash from the commercial sugarcane variety M 1176/77. The height of each compartment was extended with iron sheets in order to accommodate the various trash layers. Samples of trash were also oven-dried to determine the dry matter equivalents for each layer. The fourth compartment did not receive any trash cover and represented the control. Each treatment was replicated four times.

The trial was watered when required and germination counts were undertaken on a 3 day interval over a period of 3 weeks where the mean minimum and maximum temperatures was 19°C and 28 °C, respectively. The total rainfall recorded during that period was 63 mm.

**Trial III—Herbicide treatments × Sowing depths**

Trial III was initiated on 9 October 2008 and lasted 18 weeks to study the efficacy of different herbicide treatments on the germination and emergence of I. triloba sown at three dates within that period. This trial was carried out under a shed where only the roof was covered with perspex sheets and temperatures were similar to the ambient conditions. The trays (0.90 m × 0.45 m × 0.25 m) were displayed in a split-plot design with three replicates. Seven herbicide treatments (including an untreated control) were imposed as the main-plot treatment whereas the sub-plots represented three sowing depths. The trays were divided into two equal parts along the length to accommodate the two main-plot treatments; they were partitioned using metal sheets. The latter were further divided into three to represent the sub-plot treatments in which 10 seeds of I. triloba were sown at depths of 2, 6 and 10 cm. Each main-plot was afterwards sprayed with the respective herbicide treatments using the Micron Autodos precision sprayer (MSIRI, 2007) equipped with an air-injet nozzle.

The herbicide treatments consisted of atrazine @ 4.0 kg a.i./ha, atrazine + hexazinone @ 2.4 + 0.6 kg a.i./ha, sulfentrazone @ 1.5 kg a.i./ha, amicarbazone @ 1.05 kg a.i./ha, trifloxysulfuron + ametryn @ 0.037 + 1.463 kg a.i./ha and diclosulam @ 0.09 kg a.i./ha. After spraying, the trays were watered regularly.

Seed germination and emergence of the seeds sown at the start of the trial were monitored over a period of 6 weeks after which the I. triloba seedlings were harvested for dry weight determination. A second batch of I. triloba seeds was sown on the same day in the same respective treatment; the seedlings were harvested six weeks later for assessing the effects of the various herbicide treatments on emergence and development. A third batch of seeds was sown and monitored in the same way as for the first two six-week periods before dry weight determination. The respective mean minimum and maximum temperatures for each assessment period (of 6 weeks) were respectively 18, 20, 22 °C and 26, 28, 29 °C.

**Data analysis**

Statistical analyses were carried out using GenStat Release 7.2 DE (PC/Windows XP) (GenStat, 2007). In trials I and II, data for the final germination count at the end of the three-weeks study were analysed and the means were compared at P<0.05 for statistical significance. Values for the dry weights at the three dates of sampling in Trial III had to undergo the transformation \((x+0.5)^{0.5}\) to mitigate the large coefficient of variance due to the presence of zero values in the data (Steel et al., 1997). After analysis, the transformed data were de-transformed.

**Results**

**Trial I—Vine species × sowing depths**

The germination count, made 3 weeks after sowing, revealed that I. obscura and I. triloba had a significantly greater ability to germinate and emerge from the different sowing depths than I. nil (Table 1). In general, a significant reduction in the rate of seedling emergence of the three
Ipomoea spp. was apparent beyond a soil depth of 4 cm; this was more important for I. nil than the other two species with a reduction of more than 20% in the mean number of plants that emerged (Table 1).

Emergence of I. obscura and I. triloba was unaffected until their seeds were found deeper than 8 cm in the soil, causing a sharp decrease of more than 37% and 50% respectively in the mean number of seedlings (Table 1). No germination and emergence of I. nil at 12 cm depth was recorded.

Measurements revealed that the three Ipomoea species had the ability to produce longer hypocotyls in order to emerge from greater soil depths (Figure 1). Extension of the hypocotyl was particularly important when seeds were found at 4 cm in the soil or deeper.

At each depth, no difference in length of the hypocotyl was noted between the three vine species. No measurements were made for the length of the hypocotyl at 12 cm depth as only a few seedlings of I. obscura and I. triloba had emerged.

<table>
<thead>
<tr>
<th>Depth of sowing (cm)</th>
<th>Vine species</th>
<th>Germination count (mean number of plants)</th>
<th>Mean (Vine species)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I. nil</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.00</td>
<td>6.00</td>
</tr>
<tr>
<td></td>
<td>I. obscura</td>
<td>8.00</td>
<td>8.25</td>
</tr>
<tr>
<td></td>
<td>I. triloba</td>
<td>6.25</td>
<td>7.75</td>
</tr>
<tr>
<td></td>
<td>Mean (sowing depths)</td>
<td>6.42a</td>
<td>7.33a</td>
</tr>
</tbody>
</table>

Values are means of four replications. Standard error of difference (s.e.d.) of means for main plot—vine species (d.f. = 6) = 0.870 and s.e.d. of means for subplot treatments—depth of sowing (d.f. = 36) = 0.632. S.e.d. for comparing between means with same level of vine species = 2.220 (d.f. = 36). Mean values in the same row or column not sharing the same letter are significantly different at P < 0.05 (LSD test).

Fig. 1—Length of hypocotyl of Ipomoea spp. at different sowing depths.
**Trial II—Vine species × trash layer × sowing depths**

The higher ability of *I. obscura* and *I. triloba* to emerge compared to *I. nil* was again demonstrated in the second trial (Table 2).

This trial showed that, irrespective of vine species, a trash cover of 5 cm did not impede the growth of the vine species; emergence was found to be significantly reduced at 10 cm and more drastically with a 15 cm trash layer (Table 2).

**Table 2**—Combined effects of different trash layers and sowing depths on the germination of *Ipomoea* spp. seeds 3 weeks after sowing.

<table>
<thead>
<tr>
<th>Vine species</th>
<th>Trash layer (cm)</th>
<th>Sowing depths (cm)</th>
<th>Mean trash layer</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>I. nil</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No trash</td>
<td>2.75</td>
<td>4.50</td>
<td>2.30</td>
</tr>
<tr>
<td>5</td>
<td>4.50</td>
<td>3.25</td>
<td>2.75</td>
</tr>
<tr>
<td>10</td>
<td>3.00</td>
<td>1.50</td>
<td>1.05</td>
</tr>
<tr>
<td>15</td>
<td>0.75</td>
<td>0.75</td>
<td>0.30</td>
</tr>
<tr>
<td>Mean sowing depths</td>
<td>2.75</td>
<td>2.50</td>
<td>1.63</td>
</tr>
<tr>
<td><em>I. obscura</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No trash</td>
<td>4.50</td>
<td>5.00</td>
<td>3.95</td>
</tr>
<tr>
<td>5</td>
<td>6.50</td>
<td>5.00</td>
<td>4.20</td>
</tr>
<tr>
<td>10</td>
<td>2.00</td>
<td>0.75</td>
<td>1.05</td>
</tr>
<tr>
<td>15</td>
<td>0.50</td>
<td>0.25</td>
<td>0.20</td>
</tr>
<tr>
<td>Mean sowing depths</td>
<td>3.38</td>
<td>2.75</td>
<td>3.25</td>
</tr>
<tr>
<td><em>I. triloba</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No trash</td>
<td>4.50</td>
<td>7.25</td>
<td>5.25</td>
</tr>
<tr>
<td>5</td>
<td>7.00</td>
<td>7.50</td>
<td>5.25</td>
</tr>
<tr>
<td>10</td>
<td>2.00</td>
<td>0.75</td>
<td>1.10</td>
</tr>
<tr>
<td>15</td>
<td>0.00</td>
<td>0.25</td>
<td>0.05</td>
</tr>
<tr>
<td>Mean sowing depths</td>
<td>3.38</td>
<td>4.19</td>
<td>3.75</td>
</tr>
<tr>
<td>Mean vine species</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No trash</td>
<td>3.92</td>
<td>5.58</td>
<td>3.83</td>
</tr>
<tr>
<td>5</td>
<td>6.00</td>
<td>5.25</td>
<td>4.07</td>
</tr>
<tr>
<td>10</td>
<td>2.33</td>
<td>1.33</td>
<td>1.07</td>
</tr>
<tr>
<td>15</td>
<td>0.42</td>
<td>0.42</td>
<td>0.18</td>
</tr>
<tr>
<td>Mean sowing depths</td>
<td>3.17</td>
<td>3.15</td>
<td>2.88</td>
</tr>
</tbody>
</table>

Values are means of four replications. Standard error of difference (s.e.d.) of means for main plot —vine species (d.f. = 6) = 0.218, s.e.d. of means for subplot treatments – thickness of trash layer (d.f. = 27) = 0.273 and s.e.d. of means for the sub-sub-plot treatments – sowing depth (d.f. = 144) = 0.285. S.e.d. of means for the interaction between vine species × thickness of trash layer = 0.473 (d.f. = 27); for interaction between thickness of trash layer × sowing = 0.493 (d.f. = 144).

Irrespective of the vine species and trash cover, emergence was not adversely affected when seeds were sown at 4 cm depth or less (Table 2). As from 8 cm depth, emergence was significantly reduced and this was even more pronounced at 12 cm depth. These results were similar to those observed in Trial 1.

The interaction between thickness of trash cover and depth of sowing was significant. With a trash cover of up to 5 cm, no reduction in vine emergence was observed for seed sown at depths...
of less than 8 cm (Table 2). Beyond this depth, vine emergence was significantly reduced and was more pronounced at the 12 cm. As trash cover was increased to 10 cm, emergence of vines was significantly reduced when seeds were sown at depths of 4 cm or more.

With a 15 cm trash layer, emergence was significantly reduced at all depths including those seed sown at the surface. The presence of a trash cover of 5 cm was also found to be more conducive for seeds germinating from the surface.

**Trial III—Herbicide treatments × sowing depths**

**Efficacy of herbicides 6 WAS**

The residual effect of the various herbicide treatments during the first six weeks is expressed as the dry weight of all seedlings of *I. triloba* (Table 3).

Irrespective of the sowing depths, no significant difference in the efficacy of the six herbicide treatments was observed; all treated plots provided a very good level of control as compared to the untreated one.

The good control obtained for the seeds sown deeper in the trays was not necessarily due to the efficacy of the various herbicide treatments, as germination and growth were also significantly reduced at the 10 cm depth within the untreated control (Table 3).

**Table 3**—Effects of herbicide treatments 6 WAS on the emergence of *I. triloba* (expressed as detransformed data for dry mass) sown at 2, 6 and 10 cm depths. Values in parentheses represent transformed data.

<table>
<thead>
<tr>
<th>Herbicide treatments</th>
<th>kg a.i. ha⁻¹</th>
<th>Mean dry mass (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Atrazine</td>
<td>4.0</td>
<td>0.00 (0.71)</td>
</tr>
<tr>
<td>Atrazine + hexazinone</td>
<td>2.4</td>
<td>0.00 (0.71)</td>
</tr>
<tr>
<td>Sulfentrazone</td>
<td>1.5</td>
<td>0.00 (0.71)</td>
</tr>
<tr>
<td>Amicarbazone</td>
<td>1.05</td>
<td>0.13 (0.80)</td>
</tr>
<tr>
<td>Trifloxysulfuron + ametryn</td>
<td>0.037 + 1.463</td>
<td>0.02 (0.72)</td>
</tr>
<tr>
<td>Diclosulam</td>
<td>0.09</td>
<td>0.14 (0.80)</td>
</tr>
<tr>
<td>Control (untreated)</td>
<td>–</td>
<td>2.27 (1.66)</td>
</tr>
</tbody>
</table>

Values are means of three replications. Standard error of difference (s.e.d.) (transformed data) of means for main plot – herbicide treatments (d.f. = 12) = 0.069 and s.e.d. (transformed data) of means for subplot treatments – depth of sowing (d.f.= 28)= 0.053. S.e.d. of means (transformed data) for the interaction between herbicide treatment × sowing depth = 0.135 (d.f.= 40).

**Efficacy of herbicides 12 WAS**

For the second batch of seeds sown 6 WAS and harvested six weeks later, no significant differences were observed among the main-plot treatments (herbicide treatments), but a reduction in the dry weight of the seedlings emerging from a depth of 10 cm was observed (Table 4).

The interaction between herbicide treatments and sowing depth was also positive. The efficacy of the various herbicide treatments varied for seeds sown at 2 and 6 cm deep; at these depths the tank-mix hexazinone+atrazine and sulfentrazone provided the best control.

Diclosulam also showed some control of *I. triloba*; the level of control was significantly superior to the untreated control at the 6 cm depth (Table 4). At 12 WAS, the residual activity of atrazine alone and the tank-mix trifloxysulfuron+ametryn had elapsed, thus providing poor control of *I. triloba*. The emergence of *I. triloba* seeds was again suppressed when they were sown 10 cm deep in the trays.
Table 4—Effects of herbicide treatments 12 WAS on the emergence of *I. triloba* (expressed as detransformed data for dry mass) sown at 2, 6 and 10 cm depths. Values in parentheses represent transformed data.

<table>
<thead>
<tr>
<th>Herbicide treatments</th>
<th>kg a.i./ha</th>
<th>Mean dry mass (g)</th>
<th>Mean herbicide treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Atrazine</td>
<td>4.0</td>
<td>1.97 (1.57)</td>
<td>1.64 (1.46)</td>
</tr>
<tr>
<td>Atrazine + hexazinone</td>
<td>2.4 + 0.6</td>
<td>0.00 (0.71)</td>
<td>0.00 (0.71)</td>
</tr>
<tr>
<td>Sulfentrazone</td>
<td>1.5</td>
<td>0.00 (0.71)</td>
<td>0.00 (0.71)</td>
</tr>
<tr>
<td>Amicarbazone</td>
<td>1.05</td>
<td>0.86 (1.17)</td>
<td>0.51 (1.10)</td>
</tr>
<tr>
<td>Trifloxysulfuron + ametryn</td>
<td>0.037 + 1.463</td>
<td>0.87 (1.17)</td>
<td>2.20 (1.64)</td>
</tr>
<tr>
<td>Diclosulam</td>
<td>0.09</td>
<td>1.71 (1.49)</td>
<td>0.00 (0.71)</td>
</tr>
<tr>
<td>Control (untreated)</td>
<td>–</td>
<td>2.21 (1.65)</td>
<td>1.47 (1.40)</td>
</tr>
<tr>
<td>Mean sowing depths</td>
<td>–</td>
<td>0.96 (1.21)</td>
<td>0.69 (1.09)</td>
</tr>
</tbody>
</table>

Values are means of three replications. Standard error of difference (s.e.d.) (transformed data) of means for main plot – herbicide treatments (d.f. = 12) = 0.255 and s.e.d. (transformed data) of means for subplot treatments – depth of sowing (d.f. = 28) = 0.086. S.e.d. (transformed data) of means for the interaction between herbicide treatment × sowing depth = 0.316 (d.f. = 25).

**Efficacy of herbicides 18 WAS**

The residual activity of the various herbicide treatments tested over a period of 18 weeks revealed that only sulfentrazone was effective against *I. triloba*; sulfentrazone was found to be significantly superior to the control for seeds sown at a depth of 2 cm (Table 5). At 18 WAS, all seeds sown deeper than 6 cm showed no response to the herbicide treatments.

Table 5—Effects of herbicide treatments 18 WAS on the emergence of *I. triloba* (expressed as detransformed data for dry mass) sown at 2, 6 and 10 cm depths. Values in parentheses represent transformed data.

<table>
<thead>
<tr>
<th>Herbicide treatments</th>
<th>kg a.i./ha</th>
<th>Mean dry mass (g)</th>
<th>Mean herbicide treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Atrazine</td>
<td>4.0</td>
<td>1.04 (1.24)</td>
<td>0.65 (1.07)</td>
</tr>
<tr>
<td>Atrazine + hexazinone</td>
<td>2.4 + 0.6</td>
<td>0.22 (0.85)</td>
<td>0.45 (0.98)</td>
</tr>
<tr>
<td>Sulfentrazone</td>
<td>1.5</td>
<td>0.00 (0.71)</td>
<td>0.07 (0.75)</td>
</tr>
<tr>
<td>Amicarbazone</td>
<td>1.05</td>
<td>0.66 (1.08)</td>
<td>0.38 (0.94)</td>
</tr>
<tr>
<td>Trifloxysulfuron + ametryn</td>
<td>0.037 + 1.463</td>
<td>0.49 (0.99)</td>
<td>0.59 (1.44)</td>
</tr>
<tr>
<td>Diclosulam</td>
<td>0.09</td>
<td>0.28 (0.88)</td>
<td>0.16 (0.81)</td>
</tr>
<tr>
<td>Control (untreated)</td>
<td>–</td>
<td>0.60 (1.05)</td>
<td>0.27 (0.88)</td>
</tr>
<tr>
<td>Mean sowing depths</td>
<td>–</td>
<td>0.44 (0.97)</td>
<td>0.36 (0.93)</td>
</tr>
</tbody>
</table>

Values are means of three replications. Standard error of difference (s.e.d.) (transformed data) of means for main plot – herbicide treatments (d.f. = 12) = 0.069 and s.e.d. (transformed data) of means for subplot treatments – depth of sowing (d.f. = 28) = 0.060. S.e.d. (transformed data) of means for the interaction between herbicide treatment × sowing depth = 0.148 (d.f. = 39).

**Discussions and conclusions**

This study has revealed that vine species growing in sugarcane fields have the ability to emerge from depths of up to 12 cm although this was found to decrease relative to 8 cm. The three vine species displayed the same capacity for producing longer hypocotyls at depth beyond 4 cm. Roberts (1982) reported that most annual weeds, with seed weights between 0.1 and 5.0 mg, usually emerge from depths of less than 5 cm, although seedlings of larger-seeded species such as...
**Polygonum convolvulus** may do so from 10 cm or more. The seeds of *I. nil*, *I. obscura* and *I. triloba* form part of the latter category with mean seed weight of 18.6, 22.2 and 10.6 mg respectively (unpublished data). Furthermore, the bigger size of the *Ipomoea* seeds is associated with a greater food reserve enabling the seedlings to reach the surface by producing longer hypocotyl than small-seeded weed species (Roberts, 1982). Although *I. nil* produces bigger seeds than *I. triloba*, it was found to have a lower ability to germinate and emerge than the two other vine species in both Trials I and II. A recent study comparing germination and development of three vine species under three agroclimatic conditions of Mauritius has shown an interaction between species and climatic conditions (Chummun, 2009). The climatic conditions prevailing at Réduit may have been more conducive for the development of *I. obscura* and *I. triloba* as compared to *I. nil*.

The presence of a trash layer thicker than 5 cm had an adverse effect on the emergence of the vine species. This result concurs with that obtained in Brazil by Manechini *et al.* (2005) where trash cover equivalent to the 5 cm layer was ineffective in controlling *Ipomoea* species (*I. quamoclit*, *I. purpurea*, *I. grandifolia*, *I. hederifolia*, and *I. nil*).

The interaction between thickness of trash layer and sowing depth clearly indicates that vine control in sugarcane fields may be addressed by managing the thickness of the trash cover. Cane trash at 20 t/ha, representing approximately a 10 cm layer, has been found to reduce presence of *I. quamoclit*, *I. purpurea*, *I. grandifolia*, *I. hederifolia*, *I. nil* and *M. cissoides* by 82, 65, 62, 70, 60, and 88%, respectively (Azania *et al.*., 2002).

From our study, very effective control of vines may be achieved by uniform trash layers of approximately 15 cm or more; in fields where lower cane yields will result in less trash and thinner trash layers, trash windrowing may be an alternative. The latter was a common practice in Mauritius where trash was raked and aligned on alternate interrows in layers reaching 20 cm or more after green cane harvesting. This may explain partly the good control of vines obtained previously in Mauritius.

Satisfactory control of *I. triloba* was achieved by all the herbicide treatments tested only within the first six weeks. Atrazine was already ineffective at the second assessment (12 WAS) as compared to sulfentrazone and the tank-mix atrazine+hexazinone. This rapid decline in the efficacy of atrazine against vine weeds has previously been reported by Jones (2006). For a longer residual activity to control *I. triloba*, only sulfentrazone was found to be effective 18 WAS; sulfentrazone is already recommended in Mauritius for its long pre-emergence control of a broad spectrum of weeds (Seeruttun *et al.*, 2001). Although this better efficacy of sulfentrazone was restricted for seeds germinating at 2 cm depth, the option of using this herbicide for managing vine weeds may be considered, as emergence of seeds from greater depths is less important.

Although the findings of this study need to be confirmed at the field level, there is an indication that both the thickness of the trash layer and choice of the herbicide treatment are important parameters that should be taken into consideration in the development of strategies to control vines in sugarcane.

**REFERENCES**


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8


INTERACTIONS ENTRE LA PROFONDEUR DES GRAINES, L’ÉPAISSEUR DU PAILLIS ET LES TRAITEMENTS HERBICIDES SUR LES LIANESEN CANNE À SUCRE

Par

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MOTS-CLÉS : Ipomée spp., Sulfentrazone, Diclosulam, Contrôle de Pré Émergence.

Résumé

LES LIANES apparaissent de plus en plus fréquemment dans les parcelles de canne à sucre, en particulier depuis l'adoption croissante de paillis de canne (GCTB). Les mesures actuelles de contrôle ne sont pas efficaces sur ces lianes. Un projet ayant pour but de développer des stratégies de contrôle des lianes a été initié. Il inclut trois expérimentations étudiant les facteurs influençant l'apparition de trois espèces d'Ipomoea semée en barquettes. Dans le premier essai, des graines de I. triloba et de I. obscura ont germé pour des profondeurs supérieure à 8 cm tandis que la germination de I. nil était réduite à des profondeurs supérieures à 4 cm. Dans le deuxième essai, l'émergence des trois espèces de lianes fut gênée par un paillis de 5 cm tandis qu'une réduction significative de l'émergence fut observée avec des paillis de 10 cm. Une interaction entre la profondeur des graines de lianes et l'épaisseur du paillis a également été notée ; ainsi, l'émergence de graines aux profondeurs entre 2 et 4 cm fut réduite de plus de 75% avec un paillis de 10 cm d’épaisseur. Dans le troisième essai, six traitements herbicides de pré émergence comprenant l'atrazine, l’atrazine + hexazinone, sulfentrazone, amicarbazone, trifloxysulfuron + ametryn, et diclosulam ont été testés pour leur efficacité contre le I.trilobad semé à des profondeurs 2, 6 et 10 centimètres. Six semaines après pulvérisation, indépendamment de la profondeur de la graine, tous les traitements herbicides ont montré un contrôle satisfaisant des lianes. L'interaction entre le traitement herbicide et la profondeur de semis fut significative 12 semaines après pulvérisation, indépendamment des profondeurs de semis. Une germination inférieure à 5% ne fut observée qu’avec le sulfentrazone après 18 semaines. Ces résultats indiquent que l'épaisseur du paillis et le choix du traitement herbicide devraient être pris en compte dans le développement de stratégies de maîtrise des lianes en canne à sucre sous GCTB.
INTERACCIONES ENTRE PROFUNDIDAD DE SEMILLA, ESPESOR DE LA CAPA DE RESIDUOS DE COSECHA Y TRATAMIENTOS DE HERBICIDAS SOBRE LA EMERGENCIA DE MALEZAS DE ENREDADERA EN CAÑA DE AZÚCAR

Por
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PALABRAS CLAVE: Ipomoea spp, Sulfentrazone, Diclosulam, Control De Pre-Emergencia.

Resumen
Las malezas de enredadera están apareciendo con más frecuencia en los campos de caña de azúcar, en particular con el incremento en la adopción de la cobertura con residuos del corte de la caña en verde (GCTB). Las medidas de control regulares no están controlando efectivamente estas malezas. Se inició un proyecto para desarrollar estrategias para el manejo de las malezas de enredadera que incluyó tres ensayos para estudiar los factores que influyen en la emergencia de tres especies de Ipomoea sembrada en bandejas. En el primer ensayo, se encontró que las semillas de I. triloba y I. obscura emergen desde profundidades superiores a 8 cm, mientras que la germinación de I. nil se redujo con una profundidad de siembra de más de 4 cm. En el segundo ensayo, se encontró que la emergencia de las tres especies de enredadera no era afectada por una capa de residuos de 5 cm pero se observó reducción significativa cuando el grosor de la capa se incrementó a 10 cm. También se observó interacción entre la profundidad de la semilla de la enredadera y el espesor de la capa de residuos, es decir, la emergencia de las semillas a profundidades entre 2 y 4 cm, se redujo en más del 75% cuando estaban cubiertas por una capa de residuos de 10 cm. En el tercer ensayo, seis tratamientos de herbicidas en pre-emergencia, atrazina, atrazina + hexazinone, sulfentrazone, amicarbazona, trifloxysulfuron + ametryn y diclosulam fueron probados para determinar su eficacia contra I. triloba sembrada a profundidades de 2, 6 y 10 cm. A las 6 semanas después de la aspersión (SDA), independientemente de la profundidad de siembra, todos los tratamientos de herbicidas proporcionaron control satisfactorio. La interacción entre el tratamiento con herbicida y la profundidad de siembra fue significativa a las 12 SDA; independientemente de la profundidad de siembra, sólo sulfentrazone redujo a menos del 5% la germinación en un periodo de 18 SDA. Estos resultados indican que tanto el espesor de la capa de basura como la elección del tratamiento con herbicidas deben tenerse en cuenta en la elaboración de estrategias para el control de las enredaderas en la caña de azúcar bajo GCTB.
USE OF VINASSE FOR SOIL RECLAMATION AND ITS IMPACT ON
ELEMENTAL LOADS IN VERTISOL SOIL AND GROUNDWATER

By

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KEYWORDS: Vinasse, Sugarcane, Soil, Groundwater, Soil Reclamation.

Abstract
A STUDY was carried out to evaluate the contamination of soils and groundwater through the use of vinasse in the reclamation of saline soils with trace elements such as Fe, Cu, Mn and Zn to sugarcane soils. The soils at the experimental site were located in the flat area of Valle del Cauca, Colombia and consisted of the Vertisols of the Galpón series characterised with a Loam Clay texture and problems of salinity and sodicity. Vinasse containing 10% total solids was applied at the rate of 1500 m$^3$/ha. The trace element contents in the soil increased compared to their initial values but did not reach levels that are considered as deleterious to the soils. Similarly, the concentration of trace elements in groundwater was not significantly increased and remained below the threshold values according to the Colombian Environmental Legislation. In conclusion, in this type of soil there were no contamination problems with heavy elements in soil and groundwater from the application of vinasse with 10% solids on the reclamation of saline soils.

Introduction
The Colombian government approved law 693 of 2001 and the 3510 CONPES (2008) for alcohol production and use of biofuels in motor vehicles with a mixture of 10% alcohol in gasoline and 5% in diesel to reduce the effects of pollution generated by fossil fuels. Therefore, fuel ethanol distilleries were installed to meet consumption needs. The area planted with sugarcane is 208 161 ha (Cenicaña, 2007) for the production of sugar, molasses, and alcohol fuel.

The average production of ethanol for use as a fuel is 1 100 000 litres per day (Conpes 3510, 2008) and vinasse containing 10% total solids is generated as a waste product at a rate of 12 to 13 litres for every litre of ethanol that is produced. Vinasse can be produced at concentrations between 10% and 55% (Quintero, 2004) with varying amounts of organic matter and chemical oxygen demand (COD) (Rossi, 2007) which is considered as an environmental pollutant.

Numerous studies have shown that vinasse is a highly corrosive waste product with a high content of organic matter (OM), potassium (K) and calcium (Ca) (Alfaro and Alfaro, 1996; Garcia, 2007) and their contents of micro-elements such as Iron (Fe), Copper (Cu), Manganese (Mn) and Zinc (Zn) (Gnecco, 2007); in view of its high content of minerals, the vinasse has the potential to pollute soil and groundwater. However, the chemical composition of vinasse depends on the raw material used, the soil type and the process of preparing the alcohol (Rossi, 2007; Leal et al., 2003). Furthermore, it has been reported by Garcia (2007) that vinasse can be used as an amendment in the reclamation of saline and sodic soils. Vinasse is enriched with other fertiliser nutrients for use in the fertilisation of sugarcane (Quintero, 2004). The rates of application for reclamation (Garcia, 2007) and fertilisation for sugarcane are variable, as reported by Alfaro and Alfaro (2008), Quintero
(2004), and Gomez (2007) and depend on soil type, sugarcane variety and the concentration of the vinasse.

The trial was conducted in Moraima farm in the municipality of El Cerrito, Valle del Cauca, Colombia under sugarcane and pasture on Vertisol soils with problems of salinity, sodium toxicity and Loam Clay texture. The vinasse with 10% total solids was applied at a rate of 1500 m$^3$/hectare. This study seeks to assess the use of vinasse on reclamation of soils that are saline or have sodium toxicity and to evaluate its effect on contamination of soil and groundwater with heavy elements such as Fe, Cu, Mn and Zn.

**Materials and methods**

The study area is located in the municipality of El Cerrito, Valle del Cauca Department, Colombia on the Moraima farm between latitude 3°43’20.97” N and 76°23’22.46’ W near the Cauca River. It has an average temperature of 24°C, an average annual precipitation of 1200 mm and a mean annual average evaporation of 1700 mm. The project area consists of Vertisol soils of the series Galpòn (GL). This soil is saline and has problems with sodium.

In the process of reclamation a network of internal drainage with corrugated plastic pipe of 4’ diameter, 1.5 m deep and gravel filter was designed and built. Later, pools were built with 30 x 30 m dimensions and 50 cm high using a tractor and implement used in rice crops. These pools were flooded to 10 to 15 cm of vinasse. The vinasse was from the company CALSA located in Palmira (Valle), and contains 10% total solids with chemical characteristics that are shown in Table 1. The vinasse was applied every 15 days, to reach infiltration of the vinasse. This process was repeated three times to reach 1500 m$^3$/ha.

The soil samples were collected at depths 0–20, 20–40 and 40–60 cm because the cane roots are located down to 60 cm according to the studies of Dominguez (1990). The water samples were collected in the external part of the installed internal drainage. These analyses of soil and water were sent to the Chemical Laboratory at Field Providencia sugar mill. The samples of soil and water were collected after application of the vinasse 15 days later when the infiltration of the vinasse finished.

The Colombian Environmental Legislation in ordinance 1594 of 1984 was used for evaluation of soil and groundwater pollution with the vinasse application.

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>UNIT</th>
<th>AMOUNT</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>ppm</td>
<td>1278</td>
</tr>
<tr>
<td>$P_2O_5$</td>
<td>ppm</td>
<td>20</td>
</tr>
<tr>
<td>K</td>
<td>ppm</td>
<td>3525</td>
</tr>
<tr>
<td>Ca</td>
<td>ppm</td>
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<tr>
<td>Mg</td>
<td>ppm</td>
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<td>Zn</td>
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</tr>
<tr>
<td>B</td>
<td>ppm</td>
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</tr>
<tr>
<td>M.O.</td>
<td>%</td>
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</tr>
<tr>
<td>pH</td>
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</tr>
<tr>
<td>CE</td>
<td>Ds/m</td>
<td>10.0</td>
</tr>
<tr>
<td>C:N</td>
<td>–</td>
<td>12.8</td>
</tr>
</tbody>
</table>
Results and discussion

Soils

Table 2 compares the analysis of soil before and after the final application of vinasse 10%. These values are discussed one to one according to the report of laboratory analysis of soil.

Application of vinasse resulted in an increase in soil pH that ranged from 8.4 in the 0–20 cm layer up to 9.0 in the 40–60 cm layer. The pH increase is due to the oxidation of organic components of the vinasse in the soil. These values are in accord with Montenegro (2008), Bautista et al. (2000), Rodriguez and Chaves (1999).

The electrical conductivity (EC) found was 0.47 dS/m in the 0–20 cm layer; this value decreased showing a strong washing in this layer of soil. Information above is according to the study of Garcia (2007), showing a quick wash with products with high salt content and high doses. However, with vinasse applications with low doses, the EC value tends to increase, according to Bautista et al. (2000), Rodriguez and Chaves (1999) and Rossi (2007). Therefore, care must be taken with the processes of salinisation of the soil when vinasse is applied with low doses.

The Organic Matter (OM) in soil was found to be 3.15% in the 0–20 cm layer an increase over the initial value, indicating the great contribution of vinasse to soil due to high concentrations of OM. Therefore, the soil acts as a filter for the OM not to reach the groundwater. This information is consistent with Montenegro (2008), Bautista et al. (2000), Rodriguez and Chaves (1999) and Rossi (2007).

<table>
<thead>
<tr>
<th>Place</th>
<th>Initial</th>
<th>Finish</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
</tr>
<tr>
<td>0-30</td>
<td>8.00</td>
<td>8.40</td>
</tr>
<tr>
<td>30-60</td>
<td>8.40</td>
<td>8.40</td>
</tr>
<tr>
<td>0-20</td>
<td>8.40</td>
<td>8.50</td>
</tr>
<tr>
<td>20-40</td>
<td></td>
<td>9.00</td>
</tr>
<tr>
<td>40-60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DETERMINATION</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>8.00</td>
<td>8.40</td>
</tr>
<tr>
<td>EC - dS/m</td>
<td>2.70</td>
<td>0.47</td>
</tr>
<tr>
<td>OM - %</td>
<td>1.95</td>
<td>2.38</td>
</tr>
<tr>
<td>P - ppm</td>
<td>102.10</td>
<td>155.93</td>
</tr>
<tr>
<td>Exchangeable Cations (cmol/kg)</td>
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<td></td>
</tr>
<tr>
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<td>24.78</td>
<td>19.39</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>10.68</td>
<td>11.19</td>
</tr>
<tr>
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<td>0.76</td>
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</tr>
<tr>
<td>Sodium (Na)</td>
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<tr>
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</tr>
<tr>
<td>Ca/Mg</td>
<td>2.32</td>
<td>1.37</td>
</tr>
<tr>
<td>ESP</td>
<td>24.51</td>
<td>8.96</td>
</tr>
<tr>
<td>Micro Nutrients (PPM)</td>
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<td></td>
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<tr>
<td>Boro - B</td>
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<td>0.30</td>
</tr>
<tr>
<td>Copper - Cu</td>
<td>3.32</td>
<td>3.85</td>
</tr>
<tr>
<td>Iron - Fe</td>
<td>3.35</td>
<td>17.73</td>
</tr>
<tr>
<td>Manganese - Mn</td>
<td>3.97</td>
<td>6.13</td>
</tr>
<tr>
<td>Zinc - Zn</td>
<td>0.36</td>
<td>1.26</td>
</tr>
<tr>
<td>Texture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand</td>
<td>17.12</td>
<td>25.12</td>
</tr>
<tr>
<td>Silt (%)</td>
<td>41.28</td>
<td>37.28</td>
</tr>
<tr>
<td>Clay</td>
<td>41.60</td>
<td>37.60</td>
</tr>
<tr>
<td>Classification</td>
<td>ArL</td>
<td>FAr</td>
</tr>
</tbody>
</table>
Following the application of 1500 m$^3$/ha of vinasse, the increase in cation exchange capacity (CEC) in the top 0–20 cm to 27.16 cmol/kg and 37.10 cmol/kg in 40–60 cm layer indicates contributions of cations from the vinasse.

The observations made in this study were in accordance to those observed by Montenegro (2008), Bautista et al. (2000) and Rodriguez and Chaves (1999).

The exchangeable sodium percentage (ESP) changed from 5.74% in 0–20 cm layer to 18.06% in 40–60 cm layer; these percentages decreased considerably compared to the initial values of 24.51% in the 0–30 layer and 53.68% in the 30–60 cm layer.

This shows that the process of washing the soil with 1500 m$^3$/ha of vinasse in the reclamation of sodic soil is good and concurs with findings reported by García (2007) and Marulanda (1992).

**Amount of micro-elements**

The concentration of iron (Fe) found was 17.73 ppm in the 0–20 cm layer and 15.83 ppm in the 40–60 cm layer and increased with the application of 1500 m$^3$/ha of vinasse 10%. This increase in the soils is consistent with observations by Bautista et al. (2000), Montenegro (2008) and Quintero (2004). Meanwhile, the Environmental Legislation in Colombia has no records for this element in soils.

The concentration of copper (Cu) in the soil decreased to 1.85 ppm in the 0–20 cm layer while, in the 40–60 cm layer, this value increased slightly to 3.32 ppm. These values are considered low in the soil according to the Colombian Environmental Legislation that has the maximum value of 1200 ppm.

It is, therefore, considered that there is no soil contamination by copper. Increases of this element in the soil by application of the vinasse also were found by Bautista et al. (2000) and Rodriguez et al. (2003).

The concentration of manganese (Mn) found increased to 6.34 ppm in the 0–20 cm layer. The Colombian Environmental Legislation has not recorded this element as a problem in the soil. Information reported by Rodriguez and Chaves (1999), Montenegro (2008) and Bautista et al. (2000) is consistent with the increase in manganese with the applications of vinasse to soil.

The concentration of zinc (Zn) increased in the 0–20 cm layer to 1.39 ppm and to 1.28 ppm in the 40–60 cm layer. The value is low according to Colombian Environmental legislation.

Studies by Quintero (2004), Rodriguez and Chaves (1999), Bautista et al. (2000) and Montenegro (2008) found increases in zinc with the application of vinasse.

**Groundwater**

In Table 3 below are details of water analysis before and after the last application of 1500 m$^3$/ha of vinasse. These values are discussed according to water pollution and possible human consumption or agricultural use, according to Colombian Environmental Legislation.

The pH value increased from 7.5 to 7.8. These values show the increase in the washing of soluble cations with the application of vinasse. There are no restrictions with use for agriculture or livestock because the maximum value is pH 9.0.

The electrical conductivity (EC) increased over the initial data from 0.47 to 0.49 dS/m. The value established by law is less than 0.5 dS/m. We see how the water is increasing in salinity during soil reclamation with the application of vinasse.

The concentration of Sodium (Na) increased from 2.39 ppm to 5.51 ppm after application of vinasse 10%. This is in accordance with Garcia (2007).
Table 3—Water analysis.

<table>
<thead>
<tr>
<th>Place:</th>
<th>Initial</th>
<th>Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>N° Laboratory</td>
<td>237</td>
<td>238</td>
</tr>
<tr>
<td><strong>DETERMINATION</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>7.5</td>
<td>7.8</td>
</tr>
<tr>
<td>EC - dS/m</td>
<td>0.47</td>
<td>0.49</td>
</tr>
<tr>
<td><strong>SOLUBLE CATIONS (ppm)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium (Ca ++)</td>
<td>2.47</td>
<td>4.40</td>
</tr>
<tr>
<td>Magnesium (Mg ++)</td>
<td>2.67</td>
<td>4.14</td>
</tr>
<tr>
<td>Potassium (K +)</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Sodium (Na)</td>
<td>2.39</td>
<td>5.51</td>
</tr>
<tr>
<td>Total cations</td>
<td>7.58</td>
<td>14.10</td>
</tr>
<tr>
<td>SAR</td>
<td>1.49</td>
<td>2.67</td>
</tr>
<tr>
<td>Total hardness</td>
<td>257.00</td>
<td>427.00</td>
</tr>
<tr>
<td>Nitrogen - mg/I</td>
<td>6.79</td>
<td>0.14</td>
</tr>
<tr>
<td>Nitrates - mg/I</td>
<td>0.06</td>
<td>0.04</td>
</tr>
<tr>
<td>Nitrites - mg/I</td>
<td>24.40</td>
<td>7.50</td>
</tr>
<tr>
<td>COD - kg/day</td>
<td>46.00</td>
<td>36.00</td>
</tr>
<tr>
<td>Totals solids (SST) mg/l</td>
<td>50.00</td>
<td>10.00</td>
</tr>
<tr>
<td><strong>MICROELEMENTS (ppm)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boro</td>
<td>0.06</td>
<td>0.04</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>0.78</td>
<td>0.66</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>0.28</td>
<td>0.24</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>0.12</td>
<td>0.07</td>
</tr>
</tbody>
</table>

**Amount of micro-elements**

The concentration of Iron (Fe) initially was 0.78 ppm and, after the application of vinasse, the concentration was 0.66 ppm. This indicates that the groundwater did not increase its iron level after vinasse application at a dose of 1500 m³/ha. The groundwater does not meet the conditions for human use by environmental regulations. The limitation is 0.30 ppm while, for agriculture and livestock, there are no limitations for use.

The Copper (Cu) concentration was 0.02 ppm, and remained with the same value, showing that there were no inputs of this element by the application of vinasse. The value contaminant is 1.0 ppm for human consumption, 0.5 ppm for use in agriculture and 0.2 ppm for livestock; consequently this water can be used in any activity.

The Manganese (Mn) concentration found in the groundwater after the application of vinasse is 0.24 ppm, a slight decrease. According to the classification, this item should be below 0.10 ppm for human consumption and 0.20 ppm for agricultural use. The use of this water for human consumption is restricted to agricultural use and livestock and can be used with caution.

The Zinc (Zn) concentration decreased to 0.07 ppm, indicating that this element was not provided by application of vinasse to groundwater. Its limit value should be 5 ppm for human consumption; agricultural use is 2 ppm and 25 ppm for livestock.

**Conclusions**

The saline and sodic soils were reclaimed with the application of 1500 m³/ha vinasse with 10% total solids.
The concentration of heavy elements such as Cu, Zn, Mn and Fe increased in the soil with the soil reclamation with application of 1500 m$^3$/ha vinasse with 10% total solids but did not reach pollution problems.

The concentration of heavy metals such as Cu, Zn, Mn and Fe did not increase in the groundwater during the soil reclamation with application of 1500 m$^3$/ha vinasse with 10% total solids.

REFERENCES


UTILISATION DE LA VINASSE POUR LES BESOINS DU SOL ET IMPACT SUR LA CHARGE EN ELEMBTS D’UN VERTISOL ET DE LA NAPPE PHREATIQUE

Par

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Imecol S.A.

magon@yahoo.com

MOTS-CLÉS: Vinasse, Canne À Sucre, Sol,
Eau Phréatique, Besoin du Sol.

Résumé
UNE ÉTUDE a été réalisée pour évaluer la contamination des sols et de la nappe phréatique par des oligoéléments tels que le Fe, le Cu, le manganèse et le Zn, lors de l'utilisation de vinasse pour la mise en valeur de sols salins sous culture de canne à sucre. Les sols du site expérimental étaient localisés dans la zone plate de la Vallée del Cauca, en Colombie, comprenaient des Vertisols de la série de Galpón caractérisés par une texture argilo-limoneuse et des problèmes de salinité et de sodicité. De la vinasse contenant 10% de solides totaux fut épandue à raison de 1500 m³/ha. Les teneurs en oligoéléments du sol ont augmenté mais n'ont pas atteint des niveaux considérés comme nuisibles pour les sols. De même, les concentrations en oligoéléments des eaux souterraines n'ont pas été sensiblement augmenté et sont restée au-dessous des valeurs seuil selon la législation environnementale colombienne. En conclusion, sur ces sols salins, il n'y a pas eu de problèmes de contamination du sol et des eaux souterraines par les éléments métalliques issus d’épandage de vinasse contenant 10% solides totaux.

USO DE VINAZAS PARA LA RECUPERACIÓN DE SUELOS Y SU IMPACTO SOBRE LA CARGA DE ELEMENTOS MENORES EN SUELOS VERTISOLES Y EN AGUAS SUBTERRÁNEAS

Por

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PALABRAS CLAVE: Vinaza, Caña de Azúcar, Suelo,
Agua Subterránea, Recuperación del Suelo.

Resumen
SE REALIZÓ un estudio para evaluar la contaminación de suelos y aguas subterráneas al usar vinaza en la recuperación de suelos salinos con oligoelementos como Fe, Cu, Mn y Zn en suelos de caña de azúcar. Los suelos del sitio experimental se encuentran en la zona plana del Valle del Cauca, Colombia y consistieron en Vertisoles de la serie Galpón caracterizados por textura franco arcillosa y problemas de salinidad y sodicidad. Se les aplicó vinaza con el 10% de sólidos totales a una tasa de 1500 m³/ha. El contenido de elementos menores en el suelo aumentó con respecto a sus valores iniciales, pero no alcanzó niveles considerados perjudiciales para los suelos. Del mismo modo, la concentración de oligoelementos en el agua subterránea no aumentó significativamente y se mantuvo por debajo del umbral de los valores de acuerdo a la legislación ambiental colombiana. En conclusión, en este tipo de suelo que no hubo problemas de contaminación en los suelos ni en las aguas subterráneas con elementos pesados por aplicación de vinaza con 10% de sólidos para la recuperación de suelos salinos.
CONCEPTS AND VALUE OF THE NITROGEN GUIDELINES
CONTAINED IN THE AUSTRALIAN SUGAR INDUSTRY’S
‘SIX EASY STEPS’ NUTRIENT MANAGEMENT PROGRAM

By

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P.W. MOODY⁴ and P.G. ALLSOPP⁵

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KEYWORDS: Sugarcane, Nitrogen Management
Guidelines, Validation, Value.

Abstract

THE AUSTRALIAN sugar industry currently faces unprecedented scrutiny of its use of
nutrients due to initiatives to protect the Great Barrier Reef from excess nutrients and
sediment from agricultural activities along the Queensland coast. However, this quest
needs to be viewed in conjunction with the need for a sustainable sugarcane industry. A
comprehensive program for nutrient management (the SIX EASY STEPS program) has
been developed recently for the Australian sugar industry. It replaces the previous
general guidelines that did not differentiate between regions or soil types and lacked
precision. The new system supports profitable and sustainable sugarcane production,
enhances environmental awareness, and is consistent with best practice. The paper
summarises the alternative N management strategies that occur within the Australian
sugar industry. It describes best-practice nutrient management and the concepts that
underpin the SIX EASY STEPS program, and explains the principles of the N
management guidelines used within the SIX EASY STEPS program and link this to N
use efficiency. It also assesses the value of the SIX EASY STEPS N management
guidelines. Trial results presented indicate that the SIX EASY STEPS N guidelines are
robust and much more in line with the concept of sustainability than any of the other
strategies considered. Calculation of the target N-use efficiency factors across the full
range of SIX EASY STEPS N guidelines, especially when all possible sources of N
within the soil/plant environment are included, strengthens the SIX EASY STEPS as an
appropriate and fully comprehensive nutrient management package. This is confirmed
by the results of the economic analyses of data from both small plot experiments and
commercially-based replicated strip trials conducted on-farm.

Introduction

The Australian sugar industry currently faces unprecedented scrutiny of its use of nutrients
due to recent Australian and Queensland Government initiatives to protect the Great Barrier Reef
from ‘excesses’ of nitrogen, phosphorus and sediment that may be derived from agricultural
activities along the Queensland coast (Calcino et al., 2010). However, this government/political
imperative (Anon., 2008), which appears to be driven by environmentalists and lobbyists, should be
viewed in conjunction with the need for a sustainable sugarcane industry that forms the economic
backbone of many of the regional centres of tropical coastal Queensland.

Sustainable nutrient management that aims at profitable cane production in combination
with environmental responsibility (Schroeder et al., 2006) will enable both the above-mentioned
objectives to be met without disadvantaging either sector. A comprehensive approach to nutrient management, the SIX EASY STEPS program, was recently developed within the Australian sugar industry for this purpose (Schroeder et al., 2008). It replaced the previous general guidelines that did not differentiate between regions or soil types and lacked precision.

Although the government-led nutrient reduction strategy focuses on N and P outflow into the Great Barrier Reef Lagoon, this paper will only cover aspects of N management because of its prominence at present. However, it is important to note that the P and other nutrient guidelines (contained within the SIX EASY STEPS program) are also based on principles of best-practice nutrient management (Schroeder et al., 2006). In this regard, the SIX EASY STEPS program advocates the concept of ‘balanced nutrition’ that aims to have all essential plant nutrients present in sugarcane-producing soils at optimum levels.

Here we:
- summarise the alternative N management strategies that occur within the Australian sugar industry;
- describe our understanding of best-practice nutrient management and the concepts that underpin the SIX EASY STEPS program;
- explain the principles of the N management guidelines used within the SIX EASY STEPS program and link this to N use efficiency;
- report on specific studies that have been undertaken to assess the value of the SIX EASY STEPS N management guidelines.

Alternative N management strategies

Several strategies for determining N application rates occur within the industry (Schroeder et al., 2009a). They include the following, each with their own objectives and criteria (Table 1):
- Traditional (previous industry guidelines).
- Grower-developed (strategies developed by growers to minimise risk of production losses on-farm).
- SIX EASY STEPS (current BSES guidelines aimed at sustainable sugarcane production).
- N-replacement (currently under investigation by researchers working within the CSIRO).

Table 1—Different N management strategies used within the Australian sugar industry (Schroeder et al., 2009a).

<table>
<thead>
<tr>
<th>N strategy</th>
<th>Objectives</th>
<th>N input criteria</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional</td>
<td>Maximising productivity and linking N application rates to sugar price</td>
<td>Averaged industry regional production functions</td>
<td>Chapman (1994), Schroeder et al. (1998)</td>
</tr>
<tr>
<td>Grower-developed</td>
<td>Minimising risk of yield losses</td>
<td>In excess of ‘traditional’ rate or personal preferences</td>
<td>Johnson (1995), Wegener (1990)</td>
</tr>
<tr>
<td>SIX EASY STEPS</td>
<td>Sustaining sugarcane production; profitability in combination with environmental responsibility</td>
<td>District yield potentials and soil specific N mineralisation index</td>
<td>Schroeder et al. (2005), Wood et al. (2003)</td>
</tr>
<tr>
<td>Replacement</td>
<td>Minimising N application rates. Focus on the environment and N-use efficiency</td>
<td>N input based on yield and N off-take of previous crop</td>
<td>Thorburn et al. (2007, 2008)</td>
</tr>
</tbody>
</table>
The current imperative for sustainable N management has highlighted the need for the selection of the most appropriate N input strategies on-farm. Importantly, growers need to apply N at appropriate rates, which lead to neither under- nor over-fertilisation and provide the best economic returns.

**Best-practice nutrient management and the SIX EASY STEPS program**

**Best-practice nutrient management**

Although best-practice agriculture is generally considered to be a continuous improvement process, the large number of associated terms and standards often leads to a confused understanding of the overall concept. In describing best practice management, Williams and Walcott (1998) suggested that best-practice management encompasses an underlying process, appropriate changes that may (or may not) have to be sought externally, and an agreed framework for successful implementation.

In recognising these components, a contemporary definition of ‘best management practice’ (BMP) states that it is ‘an economically viable management practice that has been determined to be the most cost effective and practical means of preventing or reducing pollution and thus environmental harm’ (Smith, 2008). We suggest that best-practice nutrient management is linked directly to the concept of ‘risk’. It should be thought of as an overall combination of input strategies and processes that enables minimising the risk of losses in productivity (loss of yield), profitability (loss of income), nutrients (leaching, run-off and/or gaseous losses), and soil resources (erosion and fertility losses). Despite the apparent focus on losses, this definition also covers over-application of nutrients, or nutrients that are applied when not needed, because they could ultimately contribute to losses of nutrients and profitability.

**SIX EASY STEPS program**

The SIX EASY STEPS program is an integrated nutrient management package that enables the adoption of best-practice nutrient management on-farm (Schroeder et al., 2006). The overall objective of the program is to provide guidelines that lead to sustainable, site/soil specific and balanced nutrient management across the industry. The SIX EASY STEPS consist of:

- Knowing and understanding our soils.
- Understanding and managing nutrient processes and losses.
- Soil testing regularly.
- Adopting soil-specific nutrient management guidelines.
- Checking on the adequacy of nutrient inputs (e.g. leaf analyses).
- Keeping good records to help interpret trends in production and modify nutrient inputs when and where necessary.

The program is being delivered to industry through grower-orientated short-courses called ‘Accelerating the adoption of best-practice nutrient management’ (Schroeder et al., 2007b). These courses provide growers (and their advisors) with comprehensive details of the SIX EASY STEPS process and information on how to develop nutrient management plans for each block of cane on their farms. The training program is supported by other SIX EASY STEPS initiatives such as:

- Soil reference booklets that provide information on soil-specific nutrient management guidelines for sugarcane production within districts (Wood et al., 2003; Schroeder et al., 2007a).
- Replicated on-farm strip trials for growers to compare their current fertiliser programs with best-practice inputs for their soils (Salter et al., 2008, Schroeder et al., 2009b).
- NutriCalc, a user-friendly nutrient requirement calculator based on soil test values.
A Soil Constraints and Management Package (SCAMP) that utilises soil data to identify soil constraints to long-term productivity and profitability (Moody et al., 2008).

Development of ‘SafeGauge for Nutrients’ that aims to assess the risk of off-site losses (leaching or run-off) following fertiliser applications (Moody et al., 2008).

Research trials that investigate aspects of nutrient management not fully understood and the nutrient requirements of new farming systems (Wood et al., 2008).

Results and improvements from these activities are fed directly into the nutrient management short-course.

Principles of the N management guidelines used within the SIX EASY STEPS program

The N guidelines in the SIX EASY STEPS program are based on a combination of district yield potential and a soil N mineralisation index. The district yield potential is determined from the best possible yield averaged over all soil types within a district and is defined as the estimated highest average annual district yield (t cane/ha) multiplied by a factor of 1.2 (Schroeder et al., 2007a). This concept recognises differences in the ability of districts and regions to produce cane. The district yield potential for several districts (Wet Tropics, Herbert, Plane Creek, Bundaberg/Isis and Maryborough) is 120 t cane/ha (estimated highest average annual yield of 100 t cane/ha multiplied by 1.2). The district yield potential for the Proserpine and Mackay regions is set at 130 t cane/ha, and two values have been set for the Burdekin region depending on perceived longer-term yields: 150 t cane/ha and 180 t cane/ha.

The district yield potential is used to establish the base N application rate according to an estimate previously developed by Keating et al. (1997). They found that 1.4 kg N/t cane was required up to a cane yield of 100 t/ha and 1 kg N/t/ha thereafter. This is used to set a base-line N application rate of 160 kg N/ha for the Wet Tropics, Herbert, Plane Creek, Bundaberg/Isis and Maryborough districts, 170 kg N/ha for the Proserpine and Mackay districts, and 190 kg N/ha and 220 kg N/ha for the Burdekin region (Table 2).

<table>
<thead>
<tr>
<th>Crop</th>
<th>Soil organic carbon (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0–0.4</td>
</tr>
<tr>
<td>Replant cane and ratoon after replant</td>
<td>160</td>
</tr>
<tr>
<td>Plant cane after a grass/bare fallow</td>
<td>140</td>
</tr>
<tr>
<td>Proserpine and Mackay (district yield potential = 130 t cane/ha)</td>
<td></td>
</tr>
<tr>
<td>Replant cane and ratoon after replant</td>
<td>170</td>
</tr>
<tr>
<td>Plant cane after a grass/bare fallow</td>
<td>150</td>
</tr>
<tr>
<td>Burdekin (district yield potential = 150 t cane/ha)</td>
<td></td>
</tr>
<tr>
<td>Replant cane and ratoon after replant</td>
<td>190</td>
</tr>
<tr>
<td>Plant cane after a grass/bare fallow</td>
<td>150</td>
</tr>
<tr>
<td>Burdekin (district yield potential = 180 t cane/ha)</td>
<td></td>
</tr>
<tr>
<td>Replant cane and ratoon after replant</td>
<td>220</td>
</tr>
<tr>
<td>Plant cane after a grass/bare fallow</td>
<td>180</td>
</tr>
</tbody>
</table>
With the SIX EASY STEPS approach, inputs are then adjusted according to an N mineralisation index, which classes N inputs (Table 2) according to soil organic carbon (%) values (Schroeder et al., 2005). This produces a range of N application rates for replant (plant cane established shortly after harvest of the final ratoon in the previous crop cycle) and ratoon cane that correspond to these N mineralisation classes within each of the districts (Table 2). As plant cane requires less fertiliser N than replant and ratoon cane, a range of N application rates has also been established for plant cane that follows a bare or grass fallow (Table 2).

When the SIX EASY STEPS N guidelines are considered in terms of N-use efficiency, it has been important to define two terms:

- N-fertiliser utilisation index (kg N/t cane produced) = N applied (kg N/ha) / yield (t cane/ha)
- Fertiliser N-use efficiency factor (t cane/kg N) = yield (t cane/ha) / N applied (kg N/ha)

Management strategies aim to improve N-use efficiency by ensuring that the ‘N fertiliser utilisation index’ is as low as possible, and the ‘fertiliser N-use efficiency’ is as high as possible, without affecting productivity and profitability. The values shown in Table 2 (recommended application rates and district yield potential values) can be used to determine the SIX EASY STEPS target N fertiliser utilisation index (N application rate/district yield potential) and target fertiliser N-use efficiency (district potential yield/N application rate) values that apply to replant / ratoon cane and plant cane in each of the districts (Table 3).

**Table 3** – Target fertiliser N use efficiency and N fertiliser utilisation index values calculated for the N management guidelines in the SIX EASY STEPS program.

<table>
<thead>
<tr>
<th>Soil organic carbon (%)</th>
<th>0 – 0.4</th>
<th>0.4 – 0.8</th>
<th>0.8 – 1.2</th>
<th>1.2 – 1.6</th>
<th>1.6 – 2.0</th>
<th>2.0 – 2.4</th>
<th>&gt; 2.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet Tropics, Herbert, Plane Creek, Bundaberg/Isis, Maryborough (district yield potential = 120 t cane/ha)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recommended N: replant / ratoon cane (kg N/ha)</td>
<td>160</td>
<td>150</td>
<td>140</td>
<td>130</td>
<td>120</td>
<td>110</td>
<td>100</td>
</tr>
<tr>
<td>Target N fertiliser utilisation index (kg N / t cane)</td>
<td>1.33</td>
<td>1.25</td>
<td>1.17</td>
<td>1.08</td>
<td>1.00</td>
<td>0.92</td>
<td>0.83</td>
</tr>
<tr>
<td>Target fertiliser N use efficiency (t cane/kg N)</td>
<td>0.75</td>
<td>0.80</td>
<td>0.86</td>
<td>0.92</td>
<td>1.00</td>
<td>1.09</td>
<td>1.20</td>
</tr>
<tr>
<td>Recommended N: plant cane after a grass/bare fallow</td>
<td>140</td>
<td>130</td>
<td>120</td>
<td>110</td>
<td>100</td>
<td>90</td>
<td>80</td>
</tr>
<tr>
<td>Target N fertiliser utilisation index (kg N / t cane)</td>
<td>1.17</td>
<td>1.08</td>
<td>1.00</td>
<td>0.92</td>
<td>0.83</td>
<td>0.75</td>
<td>0.67</td>
</tr>
<tr>
<td>Target fertiliser N use efficiency (t cane/kg N)</td>
<td>0.86</td>
<td>0.92</td>
<td>1.00</td>
<td>1.09</td>
<td>1.20</td>
<td>1.33</td>
<td>1.50</td>
</tr>
</tbody>
</table>

| Proserpine and Mackay (district yield potential = 130 t cane/ha) | | | | | | | |
| Recommended N: replant / ratoon cane (kg N/ha) | 170 | 160 | 150 | 140 | 130 | 120 | 110 |
| Target N fertiliser utilisation index (kg N / t cane) | 1.31 | 1.23 | 1.15 | 1.08 | 1.00 | 0.92 | 0.85 |
| Target fertiliser N use efficiency (t cane/kg N) | 0.76 | 0.81 | 0.87 | 0.93 | 1.00 | 1.08 | 1.18 |
| Recommended N: plant cane after a grass/bare fallow | 150 | 140 | 130 | 120 | 110 | 100 | 90 |
| Target N fertiliser utilisation index (kg N / t cane) | 1.15 | 1.08 | 1.00 | 0.92 | 0.85 | 0.77 | 0.69 |
| Target fertiliser N use efficiency (t cane/kg N) | 0.87 | 0.93 | 1.00 | 1.08 | 1.18 | 1.30 | 1.44 |

| Burdekin (district yield potential = 150 t cane/ha) | | | | | | | |
| Recommended N: replant / ratoon cane (kg N/ha) | 190 | 180 | 170 | 160 | 150 | | |
| Target N fertiliser utilisation index (kg N / t cane) | 1.27 | 1.20 | 1.13 | 1.07 | 1.00 | | |
| Target fertiliser N use efficiency (t cane/kg N) | 0.79 | 0.83 | 0.88 | 0.94 | 1.00 | | |
| Recommended N: plant cane after a grass/bare fallow | 150 | 140 | 130 | 120 | 110 | | |
| Target N fertiliser utilisation index (kg N / t cane) | 1.00 | 0.93 | 0.87 | 0.80 | 0.73 | | |
| Target fertiliser N use efficiency (t cane/kg N) | 1.00 | 1.07 | 1.15 | 1.25 | 1.36 | | |

| Burdekin (district yield potential = 180 t cane/ha) | | | | | | | |
| Recommended N: replant / ratoon cane (kg N/ha) | 220 | 210 | 200 | 190 | 180 | | |
| Target N fertiliser utilisation index (kg N / t cane) | 1.22 | 1.17 | 1.11 | 1.06 | 1.00 | | |
| Target fertiliser N use efficiency (t cane/kg N) | 0.82 | 0.86 | 0.90 | 0.95 | 1.00 | | |
| Recommended N: plant cane after a grass/bare fallow | 180 | 170 | 160 | 150 | 140 | | |
| Target N fertiliser utilisation index (kg N / t cane) | 0.83 | 0.78 | 0.72 | 0.67 | 0.61 | | |
| Target fertiliser N use efficiency (t cane/kg N) | 1.20 | 1.29 | 1.38 | 1.50 | 1.64 | | |
The information in Table 3 shows that the target N fertiliser utilisation index value ranges from 1.33 kg N/t cane (for replant / ratatoule cane grown on soils with very low soil organic C in districts with a yield potential of 120 t cane/ha) to 0.61 kg N/t cane (for plant cane grown on soils with 1.6–2.0 % organic C in the higher yield potential (180 t cane/ha) areas of the Burdekin region.

As the SIX EASY STEPS program also recognises the N inputs from other sources (legume fallow crops, mill by-products, residual mineral N remaining after horticultural crops that are grown in rotation with sugarcane, irrigation water, etc), lower N fertiliser utilisation index values and higher fertilisation N-use efficiencies are used to take these into account. Examples of the calculated target values for the efficiency factors after legume fallow crops are shown in Table 4. Where the other sources of N supply enough N to meet the N requirement for sugarcane production, the N fertiliser utilisation index will be zero.

The SIX EASY STEPS program also recognises that, if a sub-district or farm consistently produces yields that are either higher or lower than the district yield potential, the baseline application rate should be adjusted upward or downward by 1 kg N per tonne of cane above the district yield potential. Such adjustments influence both target N-use efficiency factors.

Table 4—Target fertiliser N use efficiency and N fertiliser utilisation index values calculated for the N management guidelines for plant cane following legume fallow crops (Wet Tropics, Plane Creek, Bundaberg/Isis and Maryborough: district yield potential = 120 t cane/ha)

<table>
<thead>
<tr>
<th>Crop</th>
<th>Soil organic carbon (%)</th>
<th>0–0.4</th>
<th>0.4–0.8</th>
<th>0.8–1.2</th>
<th>1.2–1.6</th>
<th>1.6–2.0</th>
<th>2.0–2.4</th>
<th>&gt; 2.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant (baseline N application rate)</td>
<td>140</td>
<td>130</td>
<td>120</td>
<td>110</td>
<td>100</td>
<td>90</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Target N fertiliser utilisation index (kg N/t cane)</td>
<td>1.17</td>
<td>1.08</td>
<td>1.00</td>
<td>0.92</td>
<td>0.83</td>
<td>0.75</td>
<td>0.67</td>
<td></td>
</tr>
<tr>
<td>Target fertiliser N-use efficiency (t cane/kg N)</td>
<td>0.86</td>
<td>0.92</td>
<td>1.00</td>
<td>1.09</td>
<td>1.20</td>
<td>1.33</td>
<td>1.50</td>
<td></td>
</tr>
<tr>
<td>Plant following a poor legume fallow</td>
<td>90</td>
<td>80</td>
<td>70</td>
<td>60</td>
<td>50</td>
<td>40</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Target N fertiliser utilisation index (kg N/t cane)</td>
<td>0.75</td>
<td>0.67</td>
<td>0.58</td>
<td>0.50</td>
<td>0.42</td>
<td>0.33</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>Target fertiliser N-use efficiency (t cane/kg N)</td>
<td>1.33</td>
<td>1.50</td>
<td>1.71</td>
<td>0.92</td>
<td>2.00</td>
<td>3.00</td>
<td>4.00</td>
<td></td>
</tr>
<tr>
<td>Plant following a good legume harvested for grain</td>
<td>70</td>
<td>60</td>
<td>50</td>
<td>40</td>
<td>30</td>
<td>20</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Target N fertiliser utilisation index (kg N/t cane)</td>
<td>0.58</td>
<td>0.50</td>
<td>0.42</td>
<td>0.33</td>
<td>0.25</td>
<td>0.17</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>Target fertiliser N-use efficiency (t cane/kg N)</td>
<td>1.71</td>
<td>2.00</td>
<td>2.40</td>
<td>3.00</td>
<td>4.00</td>
<td>6.00</td>
<td>12.00</td>
<td></td>
</tr>
<tr>
<td>Plant following a good legume (not harvested)</td>
<td>Nil</td>
<td>Nil</td>
<td>Nil</td>
<td>Nil</td>
<td>Nil</td>
<td>Nil</td>
<td>Nil</td>
<td></td>
</tr>
<tr>
<td>Target N fertiliser utilisation index (kg N/t cane)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Target fertiliser N-use efficiency (t cane/kg N)</td>
<td>( \div 0 )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Assessing the value of the SIX EASY STEPS N management guidelines

A combination of small plot experiments and larger-scale on-farm replicated strip-trials has provided the means of assessing the value of the SIX EASY STEPS N management guidelines.

Small plot experiment

Data from a trial conducted in the Tully district of the Wet Tropics were recently used to assess the alternative N management strategies (Table 1) and what each of these means in terms of productivity, profitability and environmental implications (Schroeder et al., 2009a). Cumulative response curves for both cane and sugar yields were produced by summing yields from successive crops within the crop cycle and plotting these yields against cumulative N rates (Schroeder et al., 2009a). These curves were used to calculate industry partial net returns for each of the N management strategies. The N strategies that were evaluated were:

- Grower-developed (a possible grower application rate used in the Tully district).
- Traditional (previous industry guidelines as indicated by Calcino (1994)).
- SIX EASY STEPS (according to the guidelines shown in Table 2).
- N Replacement (1 kg N/t cane in the previous crop (Thorburn et al., 2007)).

The appropriate N inputs and yield data from the trial are shown in Table 5. While the grower-developed, traditional and SIX EASY STEPS approaches produced cumulative yields of 304, 305 and 303 t cane/ha, respectively, over the crop cycle (plant crop to third ratoon), the N Replacement strategy produced 277 t cane/ha over the same period. Based on sugar price (Aus$320/t sugar) and the cost of N (Aus$1.56/kg N) as applicable in June 2009, partial net returns for the N Replacement strategy were Aus$247/ha/year less than that of the SIX EASY STEPS. The grower-developed approach also resulted in Aus$36/ha/year loss in partial net return. The data (Table 5) indicated that yields did not normalise when low nitrogen inputs (such as those advocated by the N Replacement strategy) continued over the crop cycle.

The yield and N input data were used to calculate the N-use efficiency factors for each of these N management strategies (Table 6).

### Table 5—Tully trial: N inputs and cumulative cane yields for four N management strategies (Schroeder et al., 2009a).

<table>
<thead>
<tr>
<th></th>
<th>Grower-developed</th>
<th>Traditional</th>
<th>SIX EASY STEPS</th>
<th>N Replacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>N applied</td>
<td>Cumulative values</td>
<td>N applied</td>
<td>Cumulative values</td>
<td>N applied</td>
</tr>
<tr>
<td>per Crop</td>
<td></td>
<td>per crop</td>
<td></td>
<td>per crop</td>
</tr>
<tr>
<td></td>
<td>(kg/ha)</td>
<td>(kg N/ha)</td>
<td>(kg/ha)</td>
<td>(kg N/ha)</td>
</tr>
<tr>
<td></td>
<td>Cane yield</td>
<td>Cane yield</td>
<td>Cane yield</td>
<td>Cane yield</td>
</tr>
<tr>
<td></td>
<td>(t/ha)</td>
<td>(t/ha)</td>
<td>(t/ha)</td>
<td>(t/ha)</td>
</tr>
<tr>
<td>Plant</td>
<td>150</td>
<td>84</td>
<td>120</td>
<td>82</td>
</tr>
<tr>
<td></td>
<td>150</td>
<td>120</td>
<td>120</td>
<td>82</td>
</tr>
<tr>
<td>P+R1</td>
<td>180</td>
<td>330</td>
<td>151</td>
<td>160</td>
</tr>
<tr>
<td></td>
<td>160</td>
<td>280</td>
<td>150</td>
<td>140</td>
</tr>
<tr>
<td>P+R1+R2</td>
<td>180</td>
<td>510</td>
<td>236</td>
<td>440</td>
</tr>
<tr>
<td></td>
<td>160</td>
<td>440</td>
<td>229</td>
<td>140</td>
</tr>
<tr>
<td>P+R1+R2+R3</td>
<td>180</td>
<td>690</td>
<td>304</td>
<td>600</td>
</tr>
<tr>
<td></td>
<td>160</td>
<td>600</td>
<td>305</td>
<td>140</td>
</tr>
</tbody>
</table>

1 kg N/t cane in previous crop (Thorburn et al., 2007)

2 Cane yield of 117 t/ha for the last ratoon of the previous crop cycle

### Table 6—Mean N application rates, yield data, calculated N fertiliser utilisation indices (kg N/t cane) and fertiliser N-use efficiency values (t cane/kg N) for the small plot trial conducted in the Tully district (Grower-developed approach versus Traditional approach versus SIX EASY STEPS versus N Replacement)

<table>
<thead>
<tr>
<th>N strategy</th>
<th>Crop</th>
<th>N applied (kg/ha)</th>
<th>Cane yield (t/ha)</th>
<th>N fertiliser utilisation index (kg N/t cane)</th>
<th>Fertiliser N-use efficiency (t cane/kg N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grower developed</td>
<td>Plant</td>
<td>150</td>
<td>84</td>
<td>1.79</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td>P+R1</td>
<td>330</td>
<td>151</td>
<td>2.19</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td>P+R1+R2</td>
<td>510</td>
<td>236</td>
<td>2.16</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td>P+R1+R2+R3</td>
<td>690</td>
<td>304</td>
<td>2.27</td>
<td>0.44</td>
</tr>
<tr>
<td>Traditional</td>
<td>Plant</td>
<td>120</td>
<td>82</td>
<td>1.46</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td>P+R1</td>
<td>280</td>
<td>150</td>
<td>1.87</td>
<td>0.63</td>
</tr>
<tr>
<td></td>
<td>P+R1+R2</td>
<td>440</td>
<td>229</td>
<td>1.92</td>
<td>0.52</td>
</tr>
<tr>
<td></td>
<td>P+R1+R2+R3</td>
<td>600</td>
<td>305</td>
<td>1.97</td>
<td>0.51</td>
</tr>
<tr>
<td>SIX EASY STEPS</td>
<td>Plant</td>
<td>120</td>
<td>82</td>
<td>1.46</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td>P+R1</td>
<td>260</td>
<td>148</td>
<td>1.76</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>P+R1+R2</td>
<td>400</td>
<td>225</td>
<td>1.78</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td>P+R1+R2+R3</td>
<td>540</td>
<td>303</td>
<td>1.78</td>
<td>0.56</td>
</tr>
<tr>
<td>N Replacement</td>
<td>Plant</td>
<td>117</td>
<td>81</td>
<td>1.44</td>
<td>0.69</td>
</tr>
<tr>
<td></td>
<td>P+R1</td>
<td>198</td>
<td>143</td>
<td>1.38</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td>P+R1+R2</td>
<td>260</td>
<td>204</td>
<td>1.27</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>P+R1+R2+R3</td>
<td>321</td>
<td>277</td>
<td>1.16</td>
<td>0.86</td>
</tr>
</tbody>
</table>
The calculated N utilisation index values for the SIX EASY STEPS approach and the N Replacement strategy over the crop cycle (1.78 kg N/t cane and 1.16 kg N/t cane, respectively) were lower than that of the grower-developed and traditional approaches (2.27 kg N/t cane and 1.97 kg N/t cane, respectively). The grower-developed strategy would be considered wasteful of N inputs as well as being environmentally unacceptable. In this case the actual N-use efficiency was much lower than that of both the SIX EASY STEPS and the N Replacement strategies.

Although the N Replacement concept appears to be more efficient, the decrease in productivity (cane and sugar per hectare) resulted in losses in profitability compared to the SIX EASY STEPS approach. These results indicate that improvement in N fertiliser-use efficiency cannot be seen in isolation from productivity and profitability on farm. The SIX EASY STEPS approach that considers both these aspects is balanced and therefore more appropriate than systems aimed at either maximum production or being overly environmentally focused.

**Replicated demonstration strip trials**

Four participative replicated demonstration strip trials that were recently established in first ratoon cane crops in the Tully district to compare the productivity and profitability associated with three of the N input strategies identified in Table 1 (Grower-developed versus SIX EASY STEPS versus N Replacement). The N input strategies that were tested included the growers’ usual application rates, the SIX EASY STEPS guidelines (Table 2) and the N Replacement strategy (1 kg N/t cane produced in the previous crop).

An economic assessment of each N input approach was undertaken using the ‘pooled’ data from the four trials by:

- Determining the partial net return per hectare to the grower, where:
  \[
  \text{Grower partial net return} = (\text{gross income calculated from the Tully cane payment formula}) - (\text{cane yield} \times \text{estimated harvesting costs plus levies}) - (\text{fertiliser cost}) \\
  \]

- Calculating the industry (grower and miller) partial net return per hectare, where:
  \[
  \text{Industry partial net return} = (\text{sugar yield} \times \text{price of sugar}) - (\text{fertiliser cost} \times \text{application rate (kg/ha)}) - (\text{cane yield} \times \text{estimated harvesting costs plus levies})
  \]

The results of the statistical analysis and economic assessment of the pooled yield data from the four strip trials are shown in Table 7. Yields associated with the ‘grower’ and SIX EASY STEPS N inputs were not significantly different, but the N Replacement strategy resulted in yields (t cane/ha and t sugar/ha) significantly lower than those obtained from both of these approaches (across the four trial sites).

**Table 7**—Influence of different fertiliser strategies on cane yield, CCS, sugar yield and partial net returns using pooled data from the Tully SIX EASY STEPS calibration strip trials (first ratoon crop harvested 2008).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Mean N applied (kg/ha)</th>
<th>Mean cane yield (t/ha)</th>
<th>Mean CCS</th>
<th>Mean sugar yield (t/ha)</th>
<th>Grower partial net return (Aus$/ha)²</th>
<th>Industry partial net return (Aus$/ha)²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grower</td>
<td>149</td>
<td>90.7 a</td>
<td>14.97</td>
<td>13.50 a</td>
<td>2080</td>
<td>3464</td>
</tr>
<tr>
<td>6 Easy Steps</td>
<td>128</td>
<td>87.2 a</td>
<td>14.86</td>
<td>12.89 a</td>
<td>1996</td>
<td>3323</td>
</tr>
<tr>
<td>N Replacement</td>
<td>82</td>
<td>80.4 b</td>
<td>14.79</td>
<td>11.85 b</td>
<td>1879</td>
<td>3109</td>
</tr>
<tr>
<td>Probability</td>
<td>–</td>
<td>&lt;0.0001 Ns</td>
<td></td>
<td>&lt;0.0001</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>CV%</td>
<td>3.79</td>
<td>1.35</td>
<td>4.00</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

1Means with the same superscript letter in each column are not significantly different.
2Industry = total partial net return (grower plus miller).

Assumptions: sugar price = Aus$320/tonne, cost of N = Aus$1.56/kg
The grower and industry net returns indicated a decrease in value: Grower > SIX EASY STEPS > N Replacement. However, as the yields associated with the ‘grower’ and SIX EASY STEPS strategies were not significantly different from each other, the net return values were also viewed as being not different. Hence the partial net return values associated with the SIX EASY STEPS approach (grower: Aus$1996 and industry: Aus$3323) and the N Replacement strategy (grower: Aus$1879 and industry: Aus$3109) form a valid comparison. The SIX EASY STEPS approach resulted in a mean grower partial net return of Aus$117/ha and a mean industry partial net return of Aus$214/ha higher than that of the N Replacement.

Discussion and conclusions

The SIX EASY STEPS program is consistent with the defined principles of best practice management. It aims to directly minimise losses of productivity, profitability, applied nutrients and inherent soil fertility.

This is achieved through the SIX EASY STEPS framework that enables growers to tailor their nutrient inputs for their specific circumstances (particular soils, climatic and production conditions, etc). Although this paper deals almost exclusively with N, it was recognised earlier that the SIX EASY STEPS program is aimed at overall nutrient management that encourages sustainable and ‘balanced’ inputs on-farm.

Trial results presented indicate that the SIX EASY STEPS N guidelines are robust and much more in line with the concept of sustainability than the other strategies considered. The fact that these guidelines are based on a combination of district yield potential and a soil mineralisation index enables N inputs to be both district and soil specific.

Despite the use of pre-determined yield potentials within the current SIX EASY STEPS N guidelines, the program has enough flexibility to allow deviations from these values. Already, it is recognised that adjustments can be made for sub-districts or farms that consistently produce yields (over more than 15 years) that are either higher or lower than the district yield potential.

Calculation of the target N-use efficiency factors across the full range of SIX EASY STEPS N guidelines, especially when all possible sources of N within the soil/plant environment were included, indicated that appropriate N efficiencies are being targeted.

This strengthens the SIX EASY STEPS system as an appropriate and fully comprehensive nutrient management package. This was confirmed by the results of the economic analyses performed on data from both small plot experiments and commercially-based replicated strip trials conducted on-farm. Importantly, the economic viability of the SIX EASY STEPS N guidelines was illustrated for both the grower and milling sectors.

In overall terms, it is vital that the most appropriate N inputs are used within the sugarcane production system in Australia. This not only has implications for the environment, especially the Great Barrier Reef, but also for the communities of regional Queensland that are dependent on a sustainable sugar industry. It is our opinion that the SIX EASY STEPS guidelines, especially those that relate to N management, are the only viable option at present.

Acknowledgements

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REFERENCES


PRINCIPES ET VALEUR DES DIRECTIVES CONTENUES DANS LE PROGRAMME DE L’INDUSTRIE SUCRIERE AUSTRALIENNE SUR LA GESTION DE LA FERTILISATION APPELE "SIX EASY STEPS"

Par

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MOTS-CLÉS: Canne à Sucre, Directives de Gestion de l’Azote, Validation, Valeur.

DES INITIATIVES ont été mises en place pour protéger le récif de la grande barrière des éléments minéraux et des sédiments produits en excès par les activités agricoles le long de la côte du Queensland. Du fait de ces initiatives, l'industrie sucrière australienne fait face actuellement à un examen minutieux et sans précédent de l'utilisation des engrais minéraux. Cependant, l'étude de cette utilisation ne doit pas être dissociée des besoins d'une industrie sucrière durable. Un programme global de gestion de gestion de la fertilisation, appelé "SIX EASY STEPS" a été
CONCEPTOS Y VALIDEZ DE LAS RECOMENDACIONES DE NITRÓGENO CONTENIDAS EN EL PROGRAMA “SEIS PASOS SENCILLOS” PARA EL MANEJO DE NUTRIENTES DE LA INDUSTRIA AZUCARERA AUSTRALIANA

Por

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PALABRAS CLAVE: Caña de Azúcar, Recomendaciones para el Manejo de Nitrógeno, Validación, Validez.

Resumen

ACTUALMENTE la industria azucarera australiana enfrenta una vigilancia sin precedentes sobre su uso de nutrientes, debido a iniciativas para proteger la Gran Barrera de Coral del exceso de nutrientes y sedimentos provocados por las actividades agrícolas a lo largo de la costa de Queensland. Sin embargo, esta acción necesita verse en conjunto con la necesidad de una industria cañera sostenible. Recientemente se ha desarrollado un programa global para el manejo de nutrientes (el programa SEIS PASOS SENCILLOS) para la industria azucarera australiana. Éste reemplaza las recomendaciones generales previas que no diferenciaban entre regiones o tipos de suelo y carecian de precisión. El nuevo sistema fundamenta una producción cañera rentable y sostenible, aumenta la conciencia ambiental y es consistente con la aplicación de mejores prácticas. El artículo resume las estrategias alternativas para el manejo de nitrógeno dentro de la industria azucarera australiana. Describe las mejores prácticas para el manejo de nutrientes y los conceptos que fundamentan el programa SEIS PASOS SENCILLOS, explica los principios usados dentro del programa en cuanto a recomendaciones para el manejo de nitrógeno, y relaciona todo con la
eficiencia en el uso de nitrógeno. Además, se evalúa la validez de SEIS PASOS SENCILLOS para recomendaciones en el manejo de nitrógeno. Los resultados de los experimentos que se presentan indican que las recomendaciones de nitrógeno de SEIS PASOS SENCILLOS son robustas y mucho más en línea con el concepto de sostenibilidad que cualquiera de las otras estrategias consideradas. El cálculo de los factores clave en la eficiencia del uso de nitrógeno a lo largo de los SEIS PASOS SENCILLOS para recomendaciones de nitrógeno, especialmente al incluir todas las posibles fuentes de nitrógeno en el ambiente suelo/planta, refuerza al programa para que se considere como un paquete completo para el manejo de nutrientes. Esto se confirma con los resultados de análisis económicos de datos provenientes de experimentos en parcelas pequeñas y tratamientos en franjas con repeticiones, realizados en campos comerciales.
RECOVERY OF NITROGEN (15N) BY SUGARCANE FROM PREVIOUS CROP RESIDUES AND UREA FERTILISATION UNDER A MINIMUM TILLAGE SYSTEM

By

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KEYWORDS: Green-Cane, 15N Labelled Urea, Sugarcane Trash, Nitrogen Uptake, Mineralisation.

Abstract

RESIDUES of green-harvested sugarcane contribute to nutrient recycling in production systems. Therefore, better understanding of trash decomposition dynamics can help crop fertilisation management. This study was conducted during the 2006–2008 seasons in Jaboticabal, north-eastern Sao Paulo State, Brazil and aimed to evaluate the nitrogen recovery rates from the previous crop residues or from urea applied on sugarcane planting in a minimum tillage system, thus without trash and rhizome incorporation in crop renewal. Previous crop residues consisted of 9 and 3 t/ha of sugarcane trash (dry tops + leaves) and root system (roots + rhizomes) enriched with 1.07 and 0.81% 15N isotope, respectively. These contributed 51 and 33 kg/ha of N. 15N labelled trash laid on the soil surface and buried 15N-root system attempted to simulate the original field residues disposal. The SP81-3250 variety was planted with 80 kg N/ha of a 5.17% 15N-labelled urea. Recovery of sugarcane residues-N (trash-N and root system-N) or urea-N incorporated to the soil at planting were evaluated in distinct plant parts (stem, tops and dry leaves) during three consecutive harvest seasons. Recovery of urea-N was higher in the first harvest season (31% of initial N rate) and its uptake decreased in the second and third to 5% and 4%, respectively. In later harvested seasons, urea-N had probably been turned-over as soil organic matter and/or microbial biomass but remained in the soil N pool and available for plant recovery. Trash-N uptake closely resembled urea-N uptake, and only 13% of its N content was recovered in the first year, followed by 7% and 3% in the second and third seasons. Root system-N recovery was different since the second cut uptake was higher than the first followed by the third, 9% 6% and 2% respectively. Three year cumulative recovery of urea-N, trash-N and root system-N was 39%, 23% and 17%, respectively. Most recovered N was found in stems followed by tops and dry leaves.

Introduction

Brazil is the world’s largest sugarcane producer, totalling 7 million hectares of which more than 50% of harvest is performed without burning in Sao Paulo State (Unica, 2009). Sugarcane under green cane trash blanket (GCTB) has been adopted by many producers worldwide as a conservative crop system, reducing soil erosion and greenhouse gas (GHG) emissions. Likewise, minimum or no-tillage systems also present benefits in cost savings for highly competitive growers (Wood, 1991).

Residues of GCTB contribute to nutrient recycling in production systems; therefore, better understanding of trash decomposition dynamics can help crop fertilisation management. Those crop residues provide annually about 40 to 120 kg/ha of N thereby increasing the amount of organic matter and nutrients in the soil (Trivelin et al., 1996; Wood, 1991; Oliveira et al., 2002).
Nitrogen tracer (\(^{15}\text{N}\)) trials indicate that fertiliser-N recovery by the sugarcane crop varies from 5% to 40% (Basanta et al., 2003; Franco, 2008; Gava et al., 2005; Meier et al., 2006; Trivelin et al., 1996). These low recovery rates might be due to N losses from soil by denitrification and/or ammonia volatilisation, and gaseous losses from leaf canopy of plants (Trivelin et al., 1996) and microbial immobilisation of N in the soil (Gava et al., 2005; Oliveira et al., 2002).

Crop residues mineralisation is dependent on environmental factors such as temperature, soil moisture and aeration. Nevertheless, chemical composition of residues such as C:N ratio, lignin, cellulose, hemicellulose, and polyphenols content also play an important role in trash decomposition and nutrient dynamics (Janzen et al., 1988; Meier et al., 2006; Oliveira et al., 2002).

Sugarcane trash presents on average 390 to 450 g/kg of carbon and 4.6 to 6.5 g/kg of N, thus a C:N ratio about 100. Under these conditions, a strong immobilisation of soil N by microbial biomass and a reduced net N mineralisation for the subsequent growing season after harvested unburned sugarcane is expected, as pointed out by several trials using \(^{15}\text{N}\) tracer (Franco, 2008; Gava et al., 2005; Ng Kee Kwong et al., 1987; Oliveira et al., 2002; Meier et al., 2006).

Nitrogen recovery from crop residues incorporated into the soil varies from 2.4% to 15%. The recovery rate depends basically on residues quality regarding N content, higher than 20 g/kg and a C:N ratio lower than 25. This allows faster mineralisation compared to N immobilisation and enables higher N uptake by plants from those organic sources (Ng Kee Kwong et al., 1987; Janzen et al., 1988; Chapman et al., 1992; Gava et al., 2005).

Most studies have considered only one or two harvest seasons to evaluate the effect of N uptake from fertilisers and crop residues. This study was conducted in north-eastern Sao Paulo State, Brazil and aimed to evaluate nitrogen recovery rates from the previous-crop residues and from urea applied to sugarcane under a minimum tillage system during three consecutive harvest seasons, 2006 to 2008.

Material and methods

Location, trial design and \(^{15}\text{N}\) labelled fertiliser/crop residues

The trial was planted on March 2nd, 2005 in Jaboticabal county, north-eastern Sao Paulo State (Lat 21°17’S, Long 48°12’W) on a clayey Typic Hapludox under minimum tillage system. The previous sugarcane crop, 5th ratoon of RB855536 variety, had been desiccated with herbicide and succeeded by a single subsoiling operation, attempting to preserve previous crop residues on the soil surface.

Soil 0–25 cm layer analysis indicated: 135, 227 and 628 g/kg of total sand, silt and clay, respectively, pH\(_{\text{(CaCl2)}}\) 5.2; OM (g/dm\(^3\)) 31; P (mg/dm\(^3\)) 42 and K, Ca, Mg, and CEC, 3.1, 31, 9, 77.4 (mmolc/dm\(^3\)), respectively.

A randomised block design was adopted with four replicates of twelve rows with 15 m length and spaced 1.5 m apart. Plant-cane fertilisation (N:P\(_2\text{O}_5\):K\(_2\text{O}\)) was 80:120:120 with a planting density of twelve viable buds per metre of SP81-3250 variety. On ratoons, fertilisation was only KCl (150 kg/ha K\(_2\text{O}\)) applied as a row top dressing after each harvest.

In each plot replicate for plant-cane, micro plots comprising 2.0 m length furrows were assembled and a 5.17% \(^{15}\text{N}\) enriched urea was buried as done with ordinary urea in the remaining plot area (Trivelin et al., 1994).

Attempting to simulate past crop residues left on the soil surface, hereafter known as previous crop trash (PCT) and rhizomes (PCR), a small plot of the previous variety (RB855536) was cropped outside this trial, and the plants were labelled by foliar spraying with a 28% \(^{15}\text{N}\) urea solution, according to Faroni et al. (2007). The achieved concentrations of C, N (g/kg) and \(^{15}\text{N}\) (%) on PCT and PCR were 402, 5.7, 1.07% and 334, 6.6, 0.81%, respectively. Thus, C:N ratios on those materials were around 71:1 for PCT and 51:1 for PCR.
Furthermore, dry leaves and rhizomes were harvested out of this plot in order to assemble other $^{15}$N labelled residues micro plots (2.0 x 1.5 m), settled separately in each replication. To simulate the original disposal of crop residues, 9 t/ha of PCT was laid on soil surface and 3 t/ha of PCR was buried into soil as in Franco (2008). Thus, the total N (kg/ha) added by urea, PCT and PCR were 80, 51 and 33, respectively.

Rainfall during the studied seasons was: 1767, 1715 and 1367 mm for plant-cane, first and second ratoons, respectively. Average maximum and minimum temperatures (ºC) in these seasons were 30.4 and 18.0, respectively.

**Harvesting, sampling and statistical analysis**

The trial has been conducted over three consecutive harvest seasons: 18 month plant-cane was harvested on August 10th, 2006 and first and second 12 month ratoons on August 21st, 2007 and 25th July, 2008, respectively. Agro industrial yield data were evaluated but will not be discussed in this paper.

Harvest of urea, PCT and PCR micro plots comprised the collection of cane in 1.0 m of the central and two adjacent rows, in the same contiguous position as described in Trivelin et al. (1994) and performed in several trials (Trivelin et al., 1996; Basanta et al., 2003; Franco, 2008; Gava et al., 2005). All plant parts were harvested separately (stems, dry leaves and tops). Plant parts fresh mass were evaluated directly in the field with a weighing scale and crushed in mechanical forage chopper as in Franco (2008).

Homogenised sub-samples were prepared according to Trivelin et al. (1996) (65ºC drying for 72 h and finely ground on Willey type mill) for determination of total N (%) and $^{15}$N abundance analysis in a mass spectrometer model Hydra 20-20 SerCon Co., UK, coupled to an automatic N analyser ANCA-SGL (Barrie & Prosser, 1996).

Nitrogen recovery from fertiliser and crop residues was calculated using formulae described below (Trivelin et al., 1994; 1996):

$$Ndfs = \frac{(A - 0.367)}{(B - 0.367)} \times NC$$

$$R(\%) = \frac{(Ndfs)}{(NR)} \times 100;$$

where:

- $Ndfs$: N in plant part derived from $^{15}$N source (urea, PCT or PCR);
- $A$ and $B$: $^{15}$N abundances of harvested samples (plant part) and from $^{15}$N source, respectively (0.367% is the natural $^{15}$N abundance);
- $NC$: nitrogen content in each plant part (stem, dry leaves or tops);
- $R$: N recovery from a N source in each sample (plant part);
- $NR$: applied N rate (via fertiliser or crop residues).

ANOVA and F test statistical analyses were performed. Means detected as significant by the F test were compared by the Tukey test at 1 and 5% of probability.

**Results and discussion**

**Nitrogen recovery from planting fertiliser (urea)**

Plant-cane urea-N recovery was higher in the first harvest season, 24.7 kg/ha (31% of applied N) (Table 1). This result is consistent with 28% (22 kg/ha of urea-N) by plant-cane obtained by Franco (2008) who evaluated two other field trials using the same sugarcane variety and planting fertiliser rate (80 kg N-urea/ha). Bologna-Campbell (2007) also used the same N rate in a study with SP80-3280 variety planted in pots and obtained 35% of urea-N utilisation for the whole plant (above ground parts plus roots and rhizomes).

Chapman et al. (1992) also found that 32% of buried urea on planting was present in the first crop, despite the applied rate was two-fold compared with this case (160 kg/ha). Basanta et al. (2003) concluded that 63% (40 kg/ha) of N applied on planting was recovered by plant cane. Note
that those authors utilised a lower N dose (63 kg N/ha) as ammonium sulfate applied 50 days after planting. Korndorfer et al. (1997) found 53% of apparent urea-N recovery applied on plant cane measured using a non-isotopic method (difference method). Those authors emphasised this method usually overestimates real fertiliser-N uptake.

Table 1—Nitrogen (15N) recovery (R%) from fertiliser (Urea) applied at planting, previous crop trash (PCT) and rhizomes (PCR) in 2006, 2007 and 2008 growing seasons.

<table>
<thead>
<tr>
<th></th>
<th>Stems</th>
<th>Dry leaves</th>
<th>Tops</th>
<th>Above ground</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg/ha</td>
<td>R %</td>
<td>kg/ha</td>
<td>R %</td>
</tr>
<tr>
<td>UREA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>18.9</td>
<td>23.6 a**</td>
<td>3.10</td>
<td>3.90 a**</td>
</tr>
<tr>
<td>2007</td>
<td>1.25</td>
<td>1.57 b**</td>
<td>0.64</td>
<td>0.80 b**</td>
</tr>
<tr>
<td>2008</td>
<td>0.86</td>
<td>1.07 b**</td>
<td>0.60</td>
<td>0.74 b**</td>
</tr>
<tr>
<td>2006–2008</td>
<td>21.0</td>
<td>26.2</td>
<td>4.34</td>
<td>5.45</td>
</tr>
<tr>
<td>LSD</td>
<td>1.43</td>
<td>1.79</td>
<td>0.65</td>
<td>0.83</td>
</tr>
<tr>
<td>CV%</td>
<td>9.39</td>
<td>9.40</td>
<td>20.72</td>
<td>20.97</td>
</tr>
<tr>
<td>PCT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>5.90</td>
<td>11.6 a**</td>
<td>0.46</td>
<td>0.91 b**</td>
</tr>
<tr>
<td>2007</td>
<td>1.87</td>
<td>3.67 b**</td>
<td>0.70</td>
<td>1.37 a**</td>
</tr>
<tr>
<td>2008</td>
<td>0.90</td>
<td>1.77 c**</td>
<td>0.18</td>
<td>0.35 c**</td>
</tr>
<tr>
<td>2006–2008</td>
<td>8.67</td>
<td>17.0</td>
<td>1.34</td>
<td>2.63</td>
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<tr>
<td>LSD</td>
<td>0.93</td>
<td>1.82</td>
<td>0.16</td>
<td>0.31</td>
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<tr>
<td>CV%</td>
<td>14.8</td>
<td>15.1</td>
<td>16.3</td>
<td>16.2</td>
</tr>
<tr>
<td>PCR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>1.45</td>
<td>4.40 a**</td>
<td>0.30</td>
<td>0.91 b**</td>
</tr>
<tr>
<td>2007</td>
<td>1.57</td>
<td>4.75 a**</td>
<td>0.69</td>
<td>2.09 a**</td>
</tr>
<tr>
<td>2008</td>
<td>0.20</td>
<td>0.61 b**</td>
<td>0.07</td>
<td>0.21 b**</td>
</tr>
<tr>
<td>2006–2008</td>
<td>3.22</td>
<td>9.80</td>
<td>1.06</td>
<td>3.21</td>
</tr>
<tr>
<td>LSD</td>
<td>0.20</td>
<td>0.62</td>
<td>0.26</td>
<td>0.78</td>
</tr>
<tr>
<td>CV%</td>
<td>8.8</td>
<td>8.7</td>
<td>33.7</td>
<td>33.7</td>
</tr>
</tbody>
</table>

Same letters on columns are not statistically different by Tukey test * 5% and ** 1%, respectively. LSD: Least significant difference (Tukey); CV: coefficient of variation.

Slight differences of urea-N accumulation on plant-cane parts were found, compared to literature results. Data shown in this study presented higher uptake by the stems (77%) followed by tops (12%) and dry leaves (11%) (Table 1). Franco (2008) obtained 54% of total urea-N applied on stems, 22% on dry leaves and 24% on tops of plant cane, similar to Basanta et al. (2003) who concluded that 56% of planting fertiliser-N uptake was on stems, 23% dry leaves and 22% on tops. Korndorfer et al. (1997) found that 56% of urea-N uptake remained on stems; 16% on dry leaves and 28% on tops, respectively. These differences could be explained by the higher tonnage obtained in the present work (average 156 t/ha, data not shown) which could lead to higher urea-N accumulation in millable stalks. This could also reflect on N uptake by cane tops in further years since there were no significantly differences in three seasons for this specific plant part (Table 1).

The cumulative urea-N uptake in three seasons (2006 to 2008) reached 31.5 kg/ha (21 in stems, 4.5 dry leaves and 6 on tops). The overall recovery of urea-N applied at planting in three consecutive seasons was 39% of which 66% was found in stems, 14% in dry leaves and 20% in tops (Table 1). After the first year, urea-N had probably been turned-over as soil organic matter and/or microbial biomass but remained in the soil as an available N pool for plant recovery.

These results concord with those of Chapman et al. (1992) who obtained 32% of N recovery from buried urea application in the first year and an average of 5% was recovered by the crop above
ground part on the second cut. In the present results, 5% and 3.5% of urea-N was recovered in the second and third harvest seasons, respectively (Table 1). Basanta et al. (2003) concluded that 77% (49 kg/ha) of planting fertiliser-N (ammonium sulfate) was recovered after three cropping seasons. From that amount, 53% was exported by stems, 24% dry leaves and 23% by cane tops, respectively.

The urea-N uptake by the whole above ground part over time (1st to 3rd cut) was 31%, 5% and 4%, the same pattern obtained by Basanta et al. (2003), 63%, 11%, 4%, for first second and third cuts, respectively.

**Nitrogen recovery from previous crop residues (PCT and PCR)**

Nitrogen recovery from PCT and PCR by plant cane was 13% and 6%, respectively (Table 1). These results are consistent with those of Ng Kee Kwong et al. (1987) who observed up to 14% of trash-N recovery, when this residue remained for eighteen months in field conditions. Bologna-Campbell (2007) found 14% of crop residues-N utilisation by sugarcane after 12 months planting by using a mixture of sugarcane trash (tops + dry leaves) and rhizomes + roots labelled with $^{15}$N incorporated to the soil; 74% of crop residues-N remained in the soil at the end of the 1st season harvested.

PCT-N uptake decreased from the first to third cropping season, 13%, 7% and 3%; respectively. PCT-N amount found in stems was 74%, 11% in dry leaves and 15% in cane tops (Table 1). This distribution agreed with Gava et al. (2005) who found trash-N uptake as 52% in stems, 7% in dry leaves and 29% in cane tops. PCT-N uptake was closely related to urea-N recovery and was remarkably higher in the first cut, decreasing in the second and third harvest seasons (Table 1). This also indicates that the urea-N added to soil under GCTB and minimum tillage system could have enhanced crop residues mineralisation.

In contrast to PCT-N, a larger amount of PCR-N was recovered after the plant-cane cycle, 9% during the second harvest season, followed by 6% on the first and 2% on the third season (Table 1). This could have happened because this residue was previously buried into soil in a minimum tillage system environment, thus with limited aeration capacity leading to lower mineralisation rates in the first year (Janzen et al. 1988). This result differs from those obtained by Chapman et al. (1992) who stated that 4% of the N from a $^{15}$N-labelled crop residue (roots and stubbles) was assimilated by sugarcane after two cropping seasons. They mentioned that sometimes temporary flooding may lead to lower decomposition rates of crop residues and can reduce its N availability to plants.

Unburned cane and in this case, minimum tillage system, can lead sugarcane root system to be more superficial and take advantage of surface nutrients (Meier et al., 2006; Oliveira et al., 2002). PCR-N recovered by crop was 57% in stems, 19% in dry leaves and 23% in tops.

After three cropping seasons, N recovery from PCT and PCR by sugarcane aerial part was 12 and 6 kg/ha, respectively. As those residues contributed initially with 51 and 33 kg N/ha, N uptake was approximately 23% and 17% after three harvests (Table 1). Basanta et al. (2003) obtained 7 kg/ha (5%) of trash-N recovered by sugarcane in two consecutive cropping seasons, of which 51% was in stems, 24% in dry leaves and 29% in tops.

Overall N uptake from PCT and PCR found herein (23% and 17% – Table 1) are larger than ones found by Ng Kee Kwong et al. (1987) and Gava et al. (2005), 14% and 9%, respectively. This could be explained by the lower C:N ratio on residues applied during this work (PCT: 71:1 and PCR: 51:1) compared with those used by authors where C:N ratio was higher than 125:1. Furthermore, higher C:N ratios can decrease mineralisation rates as stressed by Janzen et al. (1988). Another point to consider is the total time of each trial (three seasons in this work against one in the others) and the local environment temperature, an important factor to be considered in this kind of evaluation.
It is also clear that trash composition is dependent on variety characteristics. Meier et al. (2006) used a $^{15}$N-labelled trash from Q166 variety (C:N 105:1) in their research in Queensland, Australia but stated that this ratio usually varies from 70:1 to 120:1. Oliveira et al. (2002) found C:N = 95:1 on recently harvested trashes of two distinct varieties (SP79-1011 and SP80-1842) and two locations in Sao Paulo State, Brazil. Bologna-Campbell (2007) obtained similar values of C:N ratio compared to the present work, 89:1 for trash and 57:1 for root system grown in pots.

Wood (1991) stated that unburned cane management provided 50% of overall urea-N recovery compared to less than 40% in burned cane but emphasised that variety suitability for GCTB crop management is mandatory for successful sugarcane growing.

In general, the amount of N recovered decreased in the order stems>tops>dry leaves. These results are consistent with those of Basanta et al. (2003), Gava et al. (2005) and Ng Kee Kwong et al. (1987) indicating that, despite crop residues-N having slow release and is mainly immobilised in the soil, it can become a complementary source of N for succeeding crops.

**Conclusion**

Nitrogen recovery from urea, PCT and PCR after three harvest seasons was 39%, 23% and 17%, respectively, indicating that N from crop residues is an important long-term source of nitrogen to sugarcane.

The larger portions of recovered nitrogen from urea and crop residues were found on stems followed by tops and dry leaves.

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MOBILISATION PAR LA CANNE À SUCRE DE L’AZOTE $^{15}$N PROVENANT DES RESIDUS DE RECOLTE ET DE L’UREE DANS UN SYSTÈME DE TYPE TRAVAIL DU SOL MINIMUM

Par

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MOTS CLES. Canne Récoltée en Vert, Urée Marquée $^{15}$N, Paillis de Canne à Sucre, Prélèvement d’Azote, Minéralisation.

Résumé

Les résidus de canne coupée en vert contribuent au recyclage des éléments minéraux dans les systèmes de production. Une meilleure connaissance de la dynamique de décomposition du paillis peut servir lors de la gestion de la fertilisation. Une étude fut réalisée pendant les saisons 2006-2008 à Jaboticabal, au Nord-Est de l’Etat de Sao Paolo, Brésil. Cette étude avait pour but d’évaluer les taux de récupération d’azote provenant des résidus de la récolte précédente ou de l’urée appliquée lors de la plantation de canne dans un système de type travail du sol minimum. Sans incorporation du paillis et des souches lors du renouvellement de la culture. Les résidus de la culture précédente étaient constitués de 9 et 3 T/ha de paillis de canne (feuilles et sommets secs) et du système souterrain (racines et rhizomes); enrichis respectivement avec 1.07 et 0.81 % d’isotope de $^{15}$N Ceci correspondait à 51 kg/Ha de N marqué avec $^{15}$N dans le mulch laissé en surface et à et 33 kg/Ha de système racinaire marqué avec $^{15}$N et enfoui pour représenter le système initial de résidus. La variété SP81-3250 fut plantée avec 80 kg/Ha d’azote d’urée marquée à 5.17%. La mobilisation de l’azote des résidus (paillis et parties racinaires) ou de l’azote de l’urée appliquée lors de la plantation de canne dans un système de type travail du sol minimum sans incorporation du paillis et des souches lors du renouvellement de la culture. Les résidus de la culture précédente étaient constitués de 9 et 3 T/ha de paillis de canne (feuilles et sommets secs) et du système souterrain (racines et rhizomes); enrichis respectivement avec 1.07 et 0.81 % d’isotope de $^{15}$N Ceci correspondait à 51 kg/Ha de N marqué avec $^{15}$N dans le mulch laissé en surface et à et 33 kg/Ha de système racinaire marqué avec $^{15}$N et enfoui pour représenter le système initial de résidus. La variété SP81-3250 fut plantée avec 80 kg/Ha d’azote d’urée marquée avec $^{15}$N à 5.17%. La mobilisation de l’azote des résidus (paillis et parties racinaires) ou de l’azote de l’urée incorporée à la plantation fut mesurée dans les différents organes (tiges, sommets et feuilles sèches) durant trois saisons consécutives. La mobilisation de l’azote de l’urée fut plus élevée lors du premier cycle de récolte (31% de l’azote initial) et plus faible lors des deuxième et troisième cycles de récolte de récolte avec des taux respectifs de 5 et 4%. Lors des derniers cycles, l’azote de l’urée fut probablement remobilisé dans la matière organique et/ou dans la biomasse microbienne mais resta
Recuperación de nitrógeno (15N) de residuos de cosechas previas por la caña de azúcar y fertilización con urea bajo un sistema de labranza mínima

Por

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Palabras clave: Caña en Verde, Urea Marcada con 15N, Trash de Caña de Azúcar, Absorción de Nitrógeno, Mineralización.

Resumen

En los sistemas de producción, los residuos de caña cosechada en verde contribuyen al reciclaje de nutrientes. Por ello una mejor comprensión de la dinámica de descomposición del trash puede ayudar en el manejo de la fertilización del cultivo. Este estudio se condujo durante las zafra 2006-2008 en Jaboticabal, en el noreste del estado de Sao Paulo, en Brasil. El objetivo era evaluar los índices de recuperación de nitrógeno de los residuos de cosechas previas o de urea aplicada a plantaciones de caña de azúcar bajo un sistema de labranza mínima, es decir, sin incorporación de trash y rizomas en la renovación del cultivo. Los residuos de cosechas anteriores consistieron en 9 y 3 t/ha de trash de caña de azúcar (cogollos secos + hojas) y sistemas radiculares (raíces + rizomas) enriquecidos con 1.07 y 0.81% del isótopo 15N, respectivamente. Esto aportó 51 y 33 kg/ha de N. Para simular los residuos reales de que se dispone en el campo, se colocó el trash marcado con 15N sobre el surco y los sistemas radiculares se enterraron. La variedad SP81-3250 se plantó con 80 kg N/ha de urea marcada con 5.17% de 15N. La recuperación de nitrógeno proveniente de residuos (trash y raíces) o de urea incorporada al suelo al momento de la siembra, se evaluó en diversas partes de la planta (tallos, cogollos y hojas secas) durante tres zafra consecutivas. La recuperación de N de urea fue mayor en la primera cosecha (31% del índice de N inicial) y su absorción disminuyó en la segunda y tercera cosecha a 5 y 4%, respectivamente. Probablemente el N de la urea se reincorporó al suelo como materia orgánica o biomasa microbiana en las zafra posteriores, pero permaneció en el suelo disponible para ser recuperado por la planta. La absorción del N del trash fue similar a la del N de urea y solamente el 13% de su contenido de N se recuperó el primer año, seguido de 7 y 3% en la segunda y tercera cosecha. La recuperación del N de los sistemas radiculares fue diferente, dado que la absorción durante la segunda cosecha fue mayor que la de la primera, seguida por la tercera, con 9, 6 y 2% respectivamente. La recuperación acumulada en tres años de N de urea, trash y sistemas radiculares fue 39, 23 y 17%, respectivamente. La mayor parte del N recuperado se encontró en los tallos, seguidos por los cogollos y hojas secas.

dans le pool azoté; disponible pour la mobilisation par la plante. La mobilisation de l’azote du paillis fut proche de celle de l’azote de l’urée, et seulement 13% de sa teneur en azote fut récupéré la première année, puis 7 et 3% les deux années suivantes. La mobilisation de l’azote du système racinaire fut différente puisque la mobilisation de la seconde récolte fut plus élevée que celle de la première et de la troisième à raison de 9, 6 et 2% respectivement. Les mobilisations cumulées sur 3 ans de l’azote de l’urée, du paillis et du système racinaire furent de 39, 23 et 17%, respectivement. La plus grande partie de l’azote récupéré fut mobilisée dans la tige, suivie des sommets et des feuilles.
ACIDITY NEUTRALISATION ASSESSMENT AND REMEDIATION OF A CONSTRUCTED WETLAND IN SUGARCANE LAND

By

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KEYWORDS: Acidity Remediation, Constructed Wetland, Rehabilitation for Sugarcane.

Abstract

A CONSTRUCTED wetland of six level-terraced bays has been trialled for treating acidic sugarcane land drainage arising principally from the oxidation of acid sulfate soils. A concern has been that the cane land may have been permanently degraded for future cane production due to the accumulation of acidic metal contaminants (especially iron and aluminium) stemming from this remediation technique. The site is now being remediated so that it can be returned to cane production. Following initial measurements to establish the water quality and sediment characteristics in the wetland, assessment was made of the required acidity neutralisation by liming, and these results were compared with best management practices for acid sulfate soil drains of New South Wales cane areas. Lime application and its incorporation were accompanied by removal of constructed banks and re-levelling of the cane block. The ability of the constructed wetland to neutralise acidity has been reported previously. Further assessment of water quality following rainfall and acid drainage shows the inherent neutralising capability of constructed wetlands, as determined by changes to pH, electrical conductivity, dissolved oxygen, and metal concentrations. Total acidity of surface soils (0–50 mm) was measured as being comparable with drain sediment in acid sulfate soils. Lime application, its incorporation, and re-levelling of the wetland site are within the scope of standard farmland practices. This approximately 1.6 ha constructed wetland surface was only capable of treating ~10% of the total acidity discharge from the 100 ha cane farm. The adoption of this as standard practice in acidic sugarcane drainage treatment is therefore impracticable. However, the principles shown here have potential for application in management of vegetated drains. Results show that the land used for the constructed wetland has not been permanently damaged by this trialled acidity remediation device.

Introduction

Acid sulfate soils (ASS) underlie more than 50% of the estuary floodplains used for sugarcane production in New South Wales, Australia. The sub-tropical high rainfall of these lands requires major surface drainage systems with the soils supplying significant acidity to the drainage water.

Robert Quirk operates one farm (100 ha) on ASS, and this site over the past 20 years has been the subject of much research and trialling of best management practices to reduce acidity discharge. Dr Rosalind Green completed most of her doctoral studies on the Quirk farm and its

drainage system, trialling a number of potential acidity management techniques. An important outcome of Green’s research was that, although protonic acidity ($H_3O^+$, as indicated by pH) is an important component of the drain water acidity, the main transported acidity component (>70%) is in the dissolved metals, particularly Aluminium (Al) and Iron (Fe) (see Figure 1).

These dissolved metals hydrolyse and form acidity when they precipitate, particularly in downstream waters (simplified in Equ. 1 and 2).

$$\text{Al}^{3+} + 3\text{H}_2\text{O} \rightarrow \text{Al(OH)}_3^{(s)} + 3\text{H}^+ \quad (1)$$

$$\text{Fe}^{3+} + 2\text{H}_2\text{O} \rightarrow \text{FeOOH} + 3\text{H}^+ \quad (2)$$

Managing such acidity from sulfide minerals and their oxidation products is also a major environmental issue with many mine sites. One management technique used to reduce acid mine drainage (AMD) is with constructed wetlands.

Therefore, using funds from the Australian Sugar Research and Development Corporation, a wetland of 6-terraced bays (approx. 2 ha of land with 1.6 ha of wetland surface) was constructed in 2003/4 adjacent to the drainage outlet from the 100 ha Quirk farm. A proportion (about 10%) of the drainage discharge from the farm was pumped into the uppermost bay from which it gravitated back into the farm’s outlet drain.

Characteristics and performance of this wetland have previously been reported in Quirk et al. (2009). The wetland has completed its proposed tasks and is now being returned to its former cane production.

Two major issues of concern for the NSW sugar industry are: firstly, whether the precipitation of the acidity in the wetland would permanently damage the land for future cane production, and secondly, whether such a management technique might in the future be forced upon the industry.
April 2009 wetland operation and modifications

A major problem with operation and monitoring of water quality performance in the wetland has been the need to pump water into it from the farm’s outlet drain after an appropriate amount of rain that promoted an acidity discharge event. Rainfall was often insufficient to retain water over the wetland surface, with sediments and any precipitated metals frequently drying out. At other times flooding from the adjacent Tweed River inundated the area under more than 1 m of floodwater. During periods of low rainfall, the farm’s drain water was both too little and became too saline (electrical conductivity, EC > 3 dS/m) to allow pumping into the wetland. Controlled leakage into the farm’s drain system is enabled from the adjacent semi-tidal McLeod’s Creek (EC up to 20 dS/m) so that drain-bottom sediments do not dry out and oxidise. A large capacity electrical pump at the farm drain’s outlet maintains the drain system water level sufficiently low to provide small rain event runoff storage but below that which would cause any lateral transfer of saline water under the cane crop. Generally, a rain event of about 35 mm is sufficient to fill the farm’s drain system and initiate the automatic pump.

At the end of March 2009 about 120 mm of rain occurred followed by a further 300 mm during the first week of April (see Figure 2). An intensive final monitoring program between April 7 and 24 was therefore undertaken that included shifting the wetland inlet position from Bay #1 to Bay #3. Bays #1 and #2 were then allowed to commence drying and enable vegetation and sediment sampling as a prelude to trialling acidity neutralisation and wetland rehabilitation for cane production.

Water quality monitoring was completed across the wetland during the April study period. Initially, water quality in all wetland bays was measured (pH, EC, dissolved oxygen-DO or redox potential) but on April 10th the water inlet was transferred from Bay #1 into Bay #3 as mentioned above (see Figures 3 and 4). The effect of the initial large rainfall event is seen with the input water and down through the wetland, in values of high pH and low EC. The initiation and progress of acidic inputs through the wetland is seen in Figure 3.
Towards the end of the study period, the input of less acidic (higher pH) and more brackish drain water (higher EC) can be seen.

Clearly, although acidic water was input continuously at about 100 L/min (there were some brief occasions when the pump stopped), as previously shown in Quirk et al. (2009), the wetland neutralised this acidity in the first one or two bays so that little of this acidity load exited from the wetland.

Red-brown iron precipitates on the wetland vegetation were obvious, particularly nearer the inlet points where initially reduced ferrous iron oxidised to ferric oxy-hydroxides (see Equ. 2).

The reduction of incoming dissolved sulfate to metal sulfide was seen in formation of black precipitates and objectionable odours, particularly after rain ceased and DO decreased over time.
Wetland vegetation sampling

Wetland vegetation was established by natural recruitment from apparently waterborne seeds. The main two species were couch grass (Cynodon dactylon) and common spike rush (probably Eleocharis palustris).

Both of these perennial, strongly rhizomatous species are native to Australia, although widespread elsewhere in the tropics and sub-tropics. A number of larger and woodier weed species established in the wetland over time, particularly on the wetland bay and perimeter banks. However, these weeds were controlled by weedicide wicking and spot spraying. The couch grass established best on the flat area of each bay while the Eleocharis tended to establish in the deeper water of the borrow-pits formed during bank construction (see Figure 5).
Total plant dry biomass samples of each of the two main species were taken from Bays #1 and #2. Three samples of each species were extracted using a spade, separating the root and shoot portions, bulking the sub-samples together, and oven-drying (85°C) and weighing. The total biomass of Couch was 3.17 kg/m² (about 32 t/ha, with approx. 60% shoot and 40% root); Eleocharis was 2.55 kg/m² (about 25 t/ha, with approx. 50% shoot and 50% root). These biomass yields are after more than 3 years growth; small by comparison to sugarcane and rather small by comparison to one-year irrigated pasture yields in Victoria, Australia (19–31 t/ha, shoot only; from Blaikie et al., 2002).

Wetland soil samples and contained acidity measurement

Three surface soil samples (0–50 mm) were taken by core from each of Bays #1 and #2 after diversion of the water flow. Each sample was bulked from 3 sub-samples. The samples were dried, sieved and analysed at the Tweed Laboratory (Tweed Shire Council) using the standard acid sulfate soil analytical methods of Ahern et al. (2004). The measured pH (pH_{KCl}) and total existing acidity measured by titrating to end-point pH 5.5 in a 1M KCl soil extract (‘TAA’), and the existing plus potential acidity with another such titrated extract, but additionally after oxidation with 30% hydrogen peroxide (‘TPA’), are shown in Table 1. The peroxide treatment in TPA is intended to oxidise any sulfide minerals in the sample.

Table 1—Wetland surface soil (0–50 mm) acidity analyses. Values of TAA and TPA in mol H⁺/t dry soil.

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Bay #1</th>
<th>Bay #2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (s.e.)</td>
<td></td>
</tr>
<tr>
<td>pH KCl</td>
<td>4.1</td>
<td>4.3</td>
</tr>
<tr>
<td>TAA</td>
<td>112 (16)</td>
<td>75 (35)</td>
</tr>
<tr>
<td>TPA</td>
<td>148 (30)</td>
<td>131 (47)</td>
</tr>
</tbody>
</table>

The overall mean TPA of 139 mol H⁺/t across Bays #1 and #2 equates to approx. 7 kg H₂SO₄/t soil. Assuming this represents the surface 0–50 mm of the total 1.6 ha of the wetland surface, and further that the soil bulk density is 1 t/m³, the measured acidity is the equivalent of approx. 5.6 tonnes of H₂SO₄ in the 1.6 ha. Each tonne of H₂SO₄ requires approx. 1 tonne of lime (CaCO₃) for acidity neutralisation. Using the common factor of safety of 1.5, neutralisation of the surface soil acidity, mostly sourced from inputs to the wetland, therefore, would require about 8.5
tonnes of lime (about 5.3 t/ha). This approximates the rate of lime normally applied by Robert Quirk (5 t/ha) with a plant cane crop to satisfy the NSW cane industry’s Code of Best Management Practices (CBMP) for managing acid sulfate soils. Of course, the measured surface soil acidity was from those bays where most metal-sourced acidity would have been precipitated.

**Application of constructed wetlands for acidity amelioration in sugarcane**

It is clear from these results that, having limited the input of salt to the wetland, the inputs of acidity from the farm’s drain water has not permanently damaged the soil and the land can easily be rehabilitated for cane production after adequate lime application, removal of terrace and perimeter bank by in-filling their adjacent borrow-pits, and re-establishing the laser-levelled drainage regime. The amount of acidity accumulated in the wetland over the 3 to 4 years of its intermittent operation probably had a significantly smaller effect than that of the land adjacent to cane field drains when they are cleaned and the drain sediments limed, spread, and incorporated into the cane field, as per the industry’s CBMP.

This wetland already occupied about 2% of the farm’s land area and only treated about 10% of the acid water discharge. On this basis, it might require a constructed wetland occupying up to 20% of a cane farm to treat all of the acidity discharge. Such a possible management tool is completely impracticable. However, there are still useful lessons that can be gained from this experiment, but these would require some shift in understanding and operation by cane farmers.

It is clear that acid water passing through vegetation stands has some of its acidity removed. Most drains in NSW cane lands have various vegetation growth, often including the main species (Couch and Eleocharis) identified in this wetland. In some instances, the water depth in the drain is too great for these species but there is a move being encouraged for farmers to use shallower drains.

On many occasions, farmers see the presence of any in-drain plant growth as deleterious to the passage of drainage water. Nevertheless, the drains are mostly required to remove water quickly under fairly high flow conditions.

At these times, the useful plant species we have identified are drowned-out and would cause little obstruction to flow. In the latter phase of a flood hydrograph, the flow rates are less and it is at this time that acidity discharge is greatest so the presence of in-drain plants would reduce acidity discharge. Any metal-sourced acidity precipitates would periodically be neutralised by liming during drain cleaning in accordance with industry’s CBMP.

**REFERENCES**


EVALUATION ET ASSAINISSEMENT DE L'ACIDITE PAR
UN MARAIS ARTIFICIEL DANS DES TERRES A CANNE

Par

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MOTS-CLÉS: Assainissement d'Acidité, Marais Artificiels,
Réhabilitation de la Canne à Sucre.

Résumé

Un marais artificiel de six niveaux en terrasses a été testé pour le traitement des drainages acides des terres de canne à sucre résultant principalement de l'oxydation des sols acides sulfatés. Une préoccupation a été que ces terres de canne ont été définitivement dégradées en raison de l'accumulation des contaminants métalliques acides (en particulier le fer et l'aluminium) découlant de cette technique d'assainissement. Le site a été maintenant assaini pour qu'il puisse être remis sous production cannière. Suite aux premières analyses pour établir la qualité de l'eau et les caractéristiques des sédiments dans le marais, la neutralisation de l'acidité existante par le chaulage a été évaluée, et les résultats ont été comparés avec les meilleures pratiques de gestion des sols sulfatés acides cultivés en canne dans la Nouvelle-Galles du Sud. L'application de chaux et son incorporation ont été accompagnées par l'élimination des marais construits et par un nivellement du bloc de canne. La capacité du marais artificiel pour neutraliser l'acidité ayant été démontrée précédemment, une évaluation plus approfondie de la qualité de l'eau après les pluies, et de drainage acide montre maintenant la capacité de neutralisation inhérente des zones humides artificielles, telles que indiquées par les changements de pH, de la conductivité, d’oxygène dissous, et par les concentrations des métaux. L'acidité totale des sols de surface (0–50 mm) était comparable à celle des sédiments dans l'eau de drainage des sols acides sulfatés. L’application de chaux, son incorporation, et le re-nivellement de la zone humide sont à la portée des pratiques agricoles standard. Ce marais d’environ 1.6 ha de surface a été capable de traiter seulement environ 10% de la décharge d'acidité totale provenant de 100 ha de canne. L'adoption de cette pratique comme un standard pour le traitement du drainage acide de canne à sucre n'est donc pas possible. Toutefois, les principes présentés ici ont un potentiel d'application dans la gestion de la végétation des drains. Les résultats montrent que les terres utilisées pour la construction des marais n'ont pas été endommagées de façon permanente par ce dispositif d'assainissement de l'acidité.
EVALUACIÓN DE NEUTRALIZACIÓN ÁCIDA Y REMEDIACIÓN DE UN HUMEDAL DE UNA PLANTACIÓN DE CAÑA DE AZÚCAR

Por

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PALABRAS CLAVE: Acidez, Remediación, Humedal, Rehabilitación para Caña de Azúcar.

Resumen

SE CONSTRUYÓ un humedal de seis niveles en terrazas para drenaje de tierras plantadas con caña de azúcar, acidificadas principalmente por la oxidación de suelos con sulfatos ácidos. Surgió preocupación por degradación permanente del terreno, a causa de esta técnica de remediación, para la producción futura de caña de azúcar por la acumulación de contaminantes de metales ácidos (especialmente hierro y aluminio). Actualmente el lugar se encuentra bajo remediación para devolverlo a la producción de caña. Luego de mediciones iniciales para establecer la calidad del agua y las características de los sedimentos en el humedal, se evaluó el requerimiento de cal para la neutralización de la acidez y estos resultados se compararon con las mejores prácticas de manejo del drenaje de suelos con sulfatos ácidos del área cañera de Nueva Gales del Sur. Además de la aplicación de cal y su incorporación, se eliminaron los montículos formados y se niveló el lote. Previamente se ha reportado la capacidad de los humedales para neutralizar la acidez. Una evaluación más profunda de la calidad del agua después de la lluvia y del drenaje de ácidos, muestra la capacidad de neutralización de los humedales, lo cual se observa en cambios de pH, conductividad eléctrica, oxígeno disuelto y concentración de metales. La acidez total de la superficie de los suelos (0–50 mm) es comparable con el sedimento del drenaje de suelos con sulfatos ácidos. La aplicación de cal, su incorporación y la nivelación del humedal están contempladas entre las prácticas agrícolas estándar. En este caso, la superficie del humedal, de aproximadamente 1.6 ha, tuvo capacidad para tratar únicamente alrededor del 10% de la descarga ácida total de las 100 ha de la finca cañera. La adopción de ésta como una práctica estándar en el drenaje de ácidos es, por tanto, impráctica. Sin embargo, los principios mostrados en el presente trabajo tienen potencial aplicación en el manejo de drenaje de suelos anegados. Los resultados muestran que los terrenos utilizados no presentan degradación permanente a causa de la construcción de los humedales.
EFFECT OF HARVEST METHOD ON MICROCLIMATE AND SUGARCANE YIELD IN FLORIDA AND COSTA RICA

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KEYWORDS: Green Cane, Burning, Soil Temperature, Crop Residue, Tiller Population.

Abstract

THERE IS worldwide pressure on sugarcane industries to adopt ‘green cane’ harvesting systems that do not involve burning. The objective of this study was to compare the effect of sugarcane harvest methods on cane productivity and microclimate in Florida, U.S.A. and Costa Rica. The treatments included 1) burnt cane, 2) green cane, and 3) green cane with residue management. These treatments were implemented at three sites: A) Everglades Research and Education Center (EREC), Belle Glade, Florida on a muck Histosol with high organic matter, B) Hilliard Brothers Farms, Florida on an Entisol with sandy texture, and C) Azucarera El Viejo mill in Guanacaste, Costa Rica on a clay loam Inceptisol. The green cane residue provided a buffering effect on soil temperatures (15–cm depth) at the Florida muck site. There was a trend for higher biomass yields in burnt cane when harvested early (Nov – early Jan), and a significant cumulative 3-year difference of 22 t/ha of cane favouring burnt vs. green cane treatments. However, cane yields were not different when harvested late in the season (mid-February – March). On the Florida sand site, a decline in tiller population, particularly in green cane, was linked to frost events in February, 2006. Air temperatures at 10-cm aboveground were lower in green cane during frosts, which led to significantly lower tiller population in green cane in the first ratoon crop. Cane biomass yields on sand followed similar trends to those on the muck soil with burnt cane recording higher yields when harvested early but not significantly different when harvested late. At the Inceptisol site in Costa Rica, trash content, biomass and sucrose yields were not significantly different in green vs. burnt cane in the plant cane and first ratoon crops. In Costa Rica, cane residues reduced maximum soil temperatures by 5–10°C for 3 months from harvest to canopy closure. Our results indicate that green cane residues have a significant effect on microclimate and that green cane harvest in Florida would be better suited for late rather than early harvest time periods.

Introduction

In burnt sugarcane systems, the crop is harvested annually in a process that utilises controlled fires prior to harvest to remove excess, adhering leaves on the standing stalks. The juices
of the sugarcane stalk contain the majority of sugar in the plant, whereas the topmost growing point and leaves (both green and senesced) have much lower sucrose contents. Furthermore, as much as 25 to 30 percent of the above-ground biomass in sugarcane is present as leaves and tops (commonly referred to by sugarcane growers as the cane trash) and is undesirable from the standpoint of processing for sugar and molasses. Pre-harvest burning destroys the trash, and increases the efficiency and profitability of the harvesting process (Meyer et al., 2005).

There are sound reasons based on conservation and agricultural science to effectively utilise crop residues by returning them to the soil if feasible. Important among these are the conservation and recycling of nutrients and organic matter, and the reduction of soil erosion and runoff in agricultural systems (Dominy et al., 2002).

As a result, there are incentives to experiment with alternative systems of harvesting unburned sugarcane which may show potential environmental and agronomic benefits (Kingston et al., 2005). Some of the potential benefits include: 1) improved air quality, 2) greenhouse gas reductions, 3) rainfall conservation (Morandini et al., 2005), 4) reduced soil erosion, herbicide usage and runoff (Makepeace and Williams, 1988; Prove et al., 1986), and 5) improved soil quality and nutrient recycling (Barzegar et al., 2000; Graham et al., 2002).

In green cane harvest systems, the non-commercial residues are conserved as surface mulches. Despite this benefit, there are major agricultural concerns with the green cane system because, under specific conditions, it has been shown to reduce sugarcane biomass and sugar yields due to excessive soil wetness, lower soil temperatures (Oliviera et al., 2001), slower ratoon crop regrowth rates, and possible allelopathic effects (Cock et al., 1997; Kingston et al., 2005). Heavy crop residues left on the fields may facilitate higher pathogen and pest pressures (Liu and Allsopp, 1996).

Additionally, trash residues generally impede effective cultivation. As a consequence, many sugarcane growers disk green cane residues into the soil following harvest. Modifying harvest practices at this scale could significantly impact the economics of producing and harvesting the sugarcane crop, as well as the entire agro-ecosystem of sugarcane fields.

However, agricultural, environmental, and social pressures are continuing to push sugarcane farming operations towards higher adoption of green cane harvesting systems, and many of the potential limitations may be solved or minimised through a multidisciplinary research team approach.

The Costa Rican sugarcane industry differs from the Florida industry in that the number of mills is greater (16 vs. 4) whereas the amount of sugar produced is smaller (380 000 vs. 1 520 000 tonnes in 2006/2007). The Costa Rican industry also is widely dispersed throughout the country while the Florida industry is concentrated south of Lake Okeechobee.

However, both industries are facing threats from increased urbanisation and environmental regulation that may push them towards greater implementation of green cane harvesting. Thus, it is important to generate sound scientific data on the benefits and disadvantages of green cane for both industries.

The objectives of this study were to determine the effect of different harvest management strategies (burnt cane, green cane, and green cane with residue management) in Florida and Costa Rica on sugarcane growth, yield and microclimate. An additional goal was to determine the effect of early vs. late harvest dates in Florida on sugarcane growth and yield under different harvest management.

Materials and methods

Harvest management experiments were established at 3 locations (Table 1): Everglades Research and Education Center (EREC) in Belle Glade, Florida; Hilliard Brothers Farms in

Clewiston, Florida; and Azucarera El Viejo in Guanacaste, Costa Rica. The EREC and Hilliard Brothers sites were harvested both early and late in the season whereas the El Viejo site was harvested once per season. All sites imposed different harvest management treatments including burning, green cane, and green cane with harvest residue management. The residue management treatments differed by location due to grower preference, and included raking from the crop row (EREC and Hilliard Brothers), disking between rows (Hilliard Brothers), and complete residue removal from the field (El Viejo). Due to different burn regulations between sites, the burnt treatment was implemented during daylight hours at EREC and Hilliard Brothers, whereas burns were conducted at night at El Viejo.

Table 1—Soil type, cultivar, planting and harvest dates for the 3 sites included in the study. PC, 1R and 2R refer to plant cane, first ratoon and second ratoon crops, respectively.

<table>
<thead>
<tr>
<th>Site</th>
<th>Soil type</th>
<th>Cultivar</th>
<th>Planting date</th>
<th>Harvest dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>EREC</td>
<td>Histosol (muck)</td>
<td>CP 80-1743</td>
<td>15/11/03</td>
<td>30/11/04 (Early PC) 23/03/05 (Late PC) 13/12/05 (Early 1R) 28/02/06 (Late 1R) 03/01/07 (Early 2R) 07/03/07 (Late 2R)</td>
</tr>
<tr>
<td>Hilliard Brothers</td>
<td>Entisol (sand)</td>
<td>CP 78-1628</td>
<td>15/08/04</td>
<td>20/12/05 (Early PC) 25/02/06 (Late PC) 18/12/06 (Late 1R) 23/02/07 (Late 1R) 10/12/07 (Early 2R) 12/02/08 (Late 2R)</td>
</tr>
<tr>
<td>El Viejo</td>
<td>Inceptisol (clay loam)</td>
<td>B 80-689</td>
<td>04/03/07</td>
<td>12/03/08 (PC) 18/03/09 (1R)</td>
</tr>
</tbody>
</table>

Measurements at all sites included crop residue (‘trash’) dry weights taken immediately after harvest, tiller population counts at monthly intervals, and whole-plot sugarcane biomass weights.

Plot sizes at all locations were at least 12 m wide x 300 m long to allow for adequate burning and also for efficient commercial-scale mechanical harvest and transport, as well as uniform trash deposition in the green cane treatments.

Cane yields were calculated from trailer or rail car weights recorded at the mill. Sucrose yields were calculated by established methods (Gilbert et al., 2006). Soil temperatures were recorded at 15-minute intervals at 15-cm depth within the row in Florida and at 2 and 10 cm in Costa Rica throughout the growing season. In addition, air temperature at 10-cm height above the row was recorded at 15-minute intervals from January–May at the two Florida locations.

Results and discussion

Sugarcane harvest management had a highly significant effect on crop residue deposited on the field (Table 2). Burning in standing cane resulted in 2.0–3.4 t/ha of residue whereas green cane harvest averaged 10.2–18.1 t/ha of residue remaining in the field.

The amount of residue declined in the ratoon crops at all locations, consistent with decreasing total crop biomass in the ratoons compared to the plant cane crops. There was a significant increase in residue production during late harvest at EREC but no significant difference in residue production due to harvest date at Hilliard Brothers (Table 2).

The residue levels obtained in the green cane treatments were similar to the 7–16 t/ha recorded in Argentina (Romero et al., 2007) and 7–12 t/ha obtained in Australia (Robertson and
Thorburn, 2007), but lower than reported in Columbia (Cock et al., 1997) and greater than estimated in Louisiana (Johnson et al., 2007).

Table 2—Crop residue dry weights at three sites. Data presented are mean values for harvest management treatment, crop class and date of harvest.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Residue</th>
<th>Crop class</th>
<th>Residue</th>
<th>Harvest date</th>
<th>Residue</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t/ha</td>
<td>t/ha</td>
<td>t/ha</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EREC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rake</td>
<td>18.1 a</td>
<td>Plant cane</td>
<td>16.7 a</td>
<td>Late</td>
<td>14.0 a</td>
</tr>
<tr>
<td>Green</td>
<td>17.3 a</td>
<td>1st ratoon</td>
<td>11.9 b</td>
<td>Early</td>
<td>10.9 b</td>
</tr>
<tr>
<td>Burnt</td>
<td>2.0 b</td>
<td>2nd ratoon</td>
<td>8.8 c</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>P &lt;0.001</td>
<td>P &lt;0.001</td>
<td>P 0.002</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hilliard Brothers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rake</td>
<td>17.6 a</td>
<td>Plant cane</td>
<td>15.4 a</td>
<td>Late</td>
<td>13.2 a</td>
</tr>
<tr>
<td>Green</td>
<td>16.2 a</td>
<td>1st ratoon</td>
<td>12.8 b</td>
<td>Early</td>
<td>13.3 a</td>
</tr>
<tr>
<td>Disk</td>
<td>15.9 a</td>
<td>2nd ratoon</td>
<td>11.6 b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Burnt</td>
<td>3.4 b</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>P &lt;0.001</td>
<td>P 0.001</td>
<td>P 0.78</td>
<td></td>
<td></td>
</tr>
<tr>
<td>El Viejo</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remove</td>
<td>10.8 a</td>
<td>Plant cane</td>
<td>10.4 a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td>10.2 a</td>
<td>1st ratoon</td>
<td>5.2 b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Burnt</td>
<td>2.4 b</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>P &lt;0.0001</td>
<td>P &lt;0.0001</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Soil temperature (15-cm depth) was significantly affected by harvest management at the EREC site. During cool periods early in the growing season, the presence of green cane residue led to higher minimum soil temperatures (Figure 1A), whereas, later in the season as air temperatures increased, the green cane plots recorded lower maximum soil temperatures (Figure 1B). Thus, the green cane systems led to a buffering of soil temperatures on both a diurnal and a seasonal basis. Leaf area indices were higher for the burnt treatment on muck, particularly when harvested early, which could have been due to lower soil temperatures early in the season leading to delayed emergence and growth. The buffering of soil temperature in green cane in our study concurs with soil temperature data reported from Louisiana (Viator et al., 2005), Argentina (Morandini et al., 2005) and Brazil (Oliviera et al., 2001).

![Fig. 1—Soil temperature (averaged over 15-min periods) at 15-cm depth as affected by harvest management at the EREC site during A) Early-season: January 7–13, 2005 and B) Late-season: March 11–17, 2005.](image-url)
Burnt cane treatments recorded higher cane yields (cane t/ha; TCH) than the green cane or raked treatments when harvested early at EREC; however, there were no significant yield differences between harvest management treatments when harvested late (Figure 2). Green cane harvest can be either beneficial or detrimental to sugarcane yield. Sugarcane yield increases under green cane have been documented in Brazil (Ball-Coelho et al., 1993) and Mexico (Toledo et al., 2005), whereas yield losses have been reported from Louisiana (Viator et al., 2008). In general, green cane harvest appears to be most detrimental to cane yield in cool and wet environments (Kingston et al., 2005).

Air temperatures during two freeze events in Feb, 2006 at the Hilliard Brothers site are presented in Figure 3. During cold nights, when air temperature declined below 5°C, the green cane treatments consistently recorded air temperatures that were 2–3°C lower than air temperatures in the burnt cane treatments. Lower air temperatures for a longer duration can have significant effects on plant growth if they cause freezing of plant tissue. We should note that the burnt cane treatments also recorded below-freezing temperatures on February 14, during an extremely cold freeze event. However, under the milder conditions recorded on February 13, sugarcane in the green cane plots would have been frozen whereas burnt cane would not.
The lower minimum air temperatures recorded in green cane are most likely due to trash reflectance leading to lower soil heat flux during the day, and thus less re-radiation of heat from the soil at night in the green cane treatments. This hypothesis would be supported by the higher maximum daytime temperature recorded in green cane for Feb 13 and 14 (Figure 3). To our knowledge, this is the first report of the effect of green cane residue on air temperatures within sugarcane fields.

The freeze events recorded in February, 2006 at the Hilliard Brothers site had a significant effect on tiller populations (Figure 4). Tiller populations in all treatments declined following the freezes, but the green and between-row disk ing treatments were most severely affected and took the longest to recover. These tiller population data can be explained by the air temperatures which reflect increased number and severity of freeze events when residue was allowed to remain within the row early in the growing season.

![Fig. 4—Tiller population for the different harvest management treatment for the first ratoon crop at the Hilliard Brothers site.](image)

The freeze events recorded in the first ratoon crop led to significantly higher cane (TCH) and sucrose (TSH) yields in burnt cane compared to the other harvest management treatments at the Hilliard Brothers site. However, 3-year cumulative yields across plant cane through to second ratoon crops were not significantly different (Table 3).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>First ratoon early TCH</th>
<th>First ratoon early TSH</th>
<th>3-year cumulative TCH</th>
<th>3-year cumulative TSH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burnt</td>
<td>76 a</td>
<td>8.9 a</td>
<td>204</td>
<td>23.0</td>
</tr>
<tr>
<td>Rake</td>
<td>71 b</td>
<td>8.1 b</td>
<td>207</td>
<td>22.8</td>
</tr>
<tr>
<td>Green</td>
<td>69 b</td>
<td>8.0 b</td>
<td>198</td>
<td>22.1</td>
</tr>
<tr>
<td>Disk</td>
<td>69 b</td>
<td>7.9 b</td>
<td>205</td>
<td>22.6</td>
</tr>
<tr>
<td>P</td>
<td>0.04</td>
<td>0.008</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

There was no significant effect on cane yields from harvest management treatments for plant cane or first ratoon at El Viejo, Costa Rica (Figure 5A), although there was a trend ($P=0.09$) towards higher sucrose yields in the first ratoon crop in burnt cane (Figure 5B). Overall, yields were lower across treatments in the first ratoon crop primarily due to flooding of the fields in October, 2008.
Fig. 5—Cane A) and sucrose B) yield for different harvest management treatments for the plant cane (PC) and first ratoon (1R) crops at the El Viejo, Costa Rica site.

The presence of crop residues also buffered soil temperature at the El Viejo, Costa Rica site. From harvest in March to canopy closure in July, crop residue reduced maximum soil temperatures by 5–10°C at 2-cm depth (Figure 6A) and by 2–5°C at 10-cm depth (Figure 6B).

Fig. 6—Daily maximum soil temperatures for different harvest management treatments at 2 (A) and 10-cm depth (B) at the El Viejo, Costa Rica site.

Conclusions

Green cane harvest buffered soil temperatures in 3 different soil types (Histosol, Entisol and Inceptisol), and also led to lower air temperatures during freeze events in Florida, indicating significant effect of harvest methods on microclimate. These microclimate effects led to significant reductions in sugarcane tiller populations and plant growth in green v. burnt cane following freeze events in Florida. Our results indicated a yield penalty in green cane systems in Florida when harvested early in the season; thus, green cane harvest should be recommended for later harvest periods. In Costa Rica, there were no significant differences in sugarcane growth and yield in green v. burnt cane in the plant cane and first ratoon crop.

REFERENCES


EFFET DE LA MÉTHODE DE RECOLTE SUR LE MICROCLIMAT ET LE RENDEMENT DE LA CANNE À SUCRE EN FLORIDE ET AU COSTA RICA

Par

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Résumé

Dans le monde entier, les industries de canne à sucre sont contraintes d'adopter les systèmes de récolte en canne verte qui évitent de brûler la canne. L’objectif de cette étude était de comparer les effets des différentes méthodes de récolte sur la productivité et le microclimat de canne en Floride et au Costa Rica. Les traitements incluaient 1) la canne brûlée, 2) la canne 2 verte et 3) la canne verte avec gestion des résidus. Ces traitements ont été appliqués sur 3 sites : A) au Centre de Recherche et de Formation des Everglades (EREC), Belle Glade, Floride sur un Histosol noir riche en matière organique, B) sur les exploitations Hilliard Brothers, Belle Glade, Floride sur un Entisol à texture sableuse, et C) sur l’exploitation de l’usine sucrière EL Viejo, à Guanacaste, Costa Rica sur un Inceptisol argilolimoneux. Les résidus de canne récoltée en vert ont provoqué un effet tampon sur les températures du sol (à 15 cm de profondeur) sur le sol noir organique de Floride. Les cannes brûlées récoltées en début de campagne (Nov.- début Janvier) produisent généralement des rendements plus élevés, avec une différence significative de 22T/ha en cumulé sur 3 ans par rapport à la canne récoltée en vert. Cependant, les rendements ne furent pas différents sur les récoltes de fin de campagne (mi-février–mars). Sur le site sableux de Floride, la diminution de la population de tiges, en particulier sur canne récoltée en vert, fut causée par les gelées de Février 2006. Les températures de l'air à 10 centimètres au dessus de la surface furent inférieures en canne verte durant les gels, ce qui a diminué significativement la population de tiges en canne verte lors de la récolte de la première repousse. Les rendements canne sur sol sableux ont suivi des tendances similaires à ceux sur le sol noir organique avec des rendements plus élevés en canne brûlée pour les récoltes de début de campagne et pas de différence pour les récoltes de fin de campagne. Sur l’Inceptisol du Costa Rica, les teneurs en résidus, les rendements canne et sucre ne furent pas différents entre canne verte et brûlée en canne plantée et repousse. Au Costa Rica, les résidus de récoltes réduisirent les températures maxima du sol de 5 à 10°C pendant 3 mois, de la récolte à la fermeture du couvert. Ces résultats montrent que les résidus de canne verte ont un effet significatif sur le microclimat et que la récolte de la canne en vert en Floride serait plus adaptée en fin plutôt qu’en début de campagne.
EFECTO DEL METODO DE COSECHA SOBRE EL MICROCLIMA Y LA PRODUCTIVIDAD DE LA CAÑA DE AZÚCAR EN LA FLORIDA Y COSTA RICA

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PALABRAS CLAVE: Caña Verde, Quema, Temperatura del Suelo, Residuos de Cosecha, Población de Tallos.

Resumen

Hay presión sobre la industria azucarera mundial para que se adopten sistemas de cosecha de “caña verde” que no involucren quemado. El objetivo de este estudio fue comparar el efecto de los métodos de cosecha de caña de azúcar de caña sobre la productividad y el microclima en Florida, EE.UU. y Costa Rica. Los tratamientos incluyeron 1) caña quemada, 2) caña verde, y 3) la caña verde con manejo de residuos. Estos tratamientos se establecieron en tres lugares: A) En Everglades Research and Education Center (EREC), Belle Glade, Florida en un Histosol, B) En Hilliard Brothers Farms, Florida, en un Entisol con textura arenosa, y C) Azucarera El Molino Viejo, en Guanacaste, Costa Rica en un Inceptisol franco-arcilloso. El residuo de la caña verde proporcionó un efecto amortiguador de las temperaturas del suelo (15 cm de profundidad) en el suelo pesado de la Florida. Hubo una tendencia a mayor rendimiento de biomasa en la caña quemada con cosecha temprana (noviembre–principios de enero), y una diferencia significativa de 22 t/ha en el acumulado de 3 años favoreciendo los tratamientos de caña quemada vs los de caña verde. Sin embargo, los rendimientos de caña no fueron diferentes cuando se cosechó al final de la temporada (mitad de febrero-marzo). En el sitio arenoso de la Florida, la disminución de la población de tallos, particularmente en caña verde, estuvo ligada a heladas que se presentaron en febrero de 2006. Las temperaturas del aire a 10-cm sobre el suelo durante las heladas fueron más bajas en caña verde que en caña quemada, lo que condujo a una significativamente menor población de tallos durante la primera soca de la caña verde. El rendimiento de biomasa de la caña en el suelo arenoso siguió tendencias similares a las de la caña quemada en el suelo pesado registrando mayor rendimiento con cosecha temprana, pero sin diferencias significativas cuando se realizó la cosecha tardía. En el suelo Inceptisol en Costa Rica, el contenido de los residuos, la biomasa y los rendimientos de sacarosa no fueron significativamente diferentes en caña verde vs. quemada en la platilla y la primera soca. En Costa Rica, los residuos de caña redujeron las temperaturas máximas del suelo de 5-10 ºC durante el periodo de 3 meses que va desde la cosecha hasta el cierre del dosel. Nuestros resultados indican que los residuos de la caña verde tienen un efecto significativo en el microclima y que la cosecha de caña verde en la Florida sería más adecuada para cosecha tardía que temprana.
AGROCLIMATIC ZONING AND CLIMATIC RISKS FOR SUGARCANE IN MEXICO—A PRELIMINARY STUDY CONSIDERING CLIMATE CHANGE SCENARIOS

By


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KEYWORDS: Sugarcane, Crop Zoning, Climate Risks, Climate Change.

Abstract

In the existing scenario of current agricultural management systems and climatic standards, a new source of uncertainties must be taken into account, namely, the temperature scenarios and water availability resulting from climate changes. In this aspect, agricultural zoning, supported by the climatic and edaphological potential of a region, and the climate scenarios, along with the associated risks, have become highly relevant. This paper considers an example of the sugarcane crop in Mexico, indicating possible potential areas for crop development, and what are the climatic risks during plant growth, based on crop zoning criteria, as well as the impact of global warming in future scenarios. The agroclimatic scope and the edaphological and climatic zoning were defined through the quantification of physical resources and the water balance parameters of different regions, indicating the relationship between energy availability, water supply and crop water demand. The study further determined the influence of climate changes in the quantification of the water balance for the regions and the effects of this anomaly in sugarcane development. The study was based on meteorological data from historic series from Mexican research institutes and from the National Meteorological Service of Mexico, accessible via the Web. The available products are: a) monthly and annual air temperature; b) monthly and annual total rainfall, c) monthly and fortnightly values of water deficit and surplus; d) drought probability at monthly and fortnightly level and maps of frost. As a result, maps of agroclimatic suitability for the various regions in Mexico were produced with the current climate standards as well as considering the increase in meteorological adversities and the change in the scenarios due to global warming. Climatic risks associated with high or low temperatures and the probability of drought events are shown for both agrometeorological and meteorological factors, with an indication of the regions that are more suitable for the development of this crop.

Introduction

In the established scenarios based on the current agricultural management systems and the climate patterns that affect development of the sugarcane crop, a new source of uncertainty must be taken into account—the temperature and water availability scenarios resulting from climate changes and/or global warming.

Despite abundant discussion and a multitude of studies indicating future scenarios related to global warming and the current modifications resulting from those possible changes, or even the anomalies due to seasonal climate variability, very little is known as a fact, especially how crops respond to a new thermal regime, the physiological and metabolic adaptations, and the consequent modifications to which crops will be subject. Therefore, it is the responsibility of different agencies...
to propose adaptation measures in order to reduce the negative effects of climate adversities. An important procedure is the establishment of public policies for agricultural development based on climatic characteristics. In that sense, agricultural zoning followed by Agro-ecological Zoning, based on the climatic and edaphic potential of a region and its associated risks, are highly relevant. It is also important to mention that the agro-ecological zoning might provide complementary information about the climatic risk in certain phases of the crop such as: high or low temperatures, drought or excess rainfall, thus indicating the climatic risk and the feasibility of success and production.

In spite of its remarkable adjustment to climatic conditions, the sugarcane plant finds its best conditions when there is a hot and humid period, with high solar radiation in the growth phase, followed by a dry period, sunny and cooler, in the maturation and harvest phases. The main factors that determine the success of the crop and its economic use are air temperature and rainfall. Studies from Bacchi and Souza (1978) indicated that, in irrigated crops, growth stopped or was irrelevant for an air temperature below 18ºC whereas, for non-irrigated crops, this temperature was 19ºC. This crop reasonably endures high temperatures of 34/35ºC for a few hours. However, steady values above 38/40ºC may affect its development through the inhibitory effect of physiological activities such as the opening of stomata and CO₂ exchange. An aspect that is still important is flowering, as it may compromise productivity. During the flowering inductive period, both the water supply and temperature regimes are critical. Minimal air temperatures (at night) below 18ºC and maximum temperatures (daytime) above 30/32ºC affect flowering negatively, that is to say, inhibit it (Pereira et al., 1983). After floral induction, the forming of new internodes ceases and the pith process of the basic tissue may start. For most varieties after flowering induction, as long as climatic conditions are suitable, the emission of panicles happens between 7 and 10 weeks. In a such a case, there is an inversion in the process of sucrose production which is directed towards panicle emission and final sugar content is reduced.

This study aims to indicate, in a preliminary form, the potential for agricultural use of the sugarcane crop in the Republic of Mexico and the climate factors that influence this potential. Additionally, a simulation of the effect of global warming on the agricultural suitability of the crop is also presented.

**Materials and methods**

The study of agricultural zoning or agro climatic suitability, followed by agro environmental zoning, comprises the determination, within a certain defined area, of the potential of agricultural use of crops in relation to their climate demands and of how much support the climate can offer in terms of temperature and water supply. It also includes evaluation of climatic risks associated with frost, water deficit, drought or high temperatures. The climate is generally the first element taken into account as it is considered a stability factor, although seasonal variations and climate variability must also be considered.

The methodology used for the definition of the appropriate areas for growth and production of sugarcane is based on studies of climate zoning of crops such as: Camargo and Ortolani (1964), Alfonsi et al. (1995), Brunini et al. (2008a); Brunini et al. (2008b); and Brunini et al, (2009). Despite being relatively work intensive, this methodology is efficient for qualitative climate comparison between the several regions of the globe to study agricultural zoning. Also, a better degree of refinement is reached when this methodology and the climate indexes are compared with indexes of crops in order to obtain the bioclimatic indexes for the referred crop. The widely known and widely used methodology in this type of agroclimatic zoning is the following:

1. Data collection and preparation of basic climatic charts representative of the region (average air temperature; annual and coldest month; and potential evapotranspiration, among others).
2. Calculation of Water Balance for the determination of the following parameters: actual evapotranspiration; water deficit and surplus based on water balance parameters according to Thornthwaite and Mather, (1955).

3. Survey of climate demands of the crop–values estimated based on climate-sugarcane qualification (Brunini, 1997 a; Brunini, 1997b);

4. Comparison of these data obtained in item 3 with the data provided in items 1 and 2 and layout of agroclimatic maps for the referred crops.

After all the processes (1 to 4), a region may be classified for the growth of a plant, in one of three following categories.

- Adequate: when macroclimate conditions are normally favourable for commercial use;
- Restricted: when climate conditions present restrictions which frequently undermine certain phases of the crop. There might be some limitation, not too severe, in terms of temperature and/or water supply;
- Inadequate: when climatic characteristics are not adequate for commercial use. In this case, there are serious limitations in terms of temperature and water supply.

**Meteorological parameters and water balance**

The source of meteorological data for the execution of the studies was the existing climatic basis made available by the National Meteorological Service of Mexico, according to access and collection of information via the WEB in March, 2009 (http://smn.cna.gob.mx).

The basic information obtained was the average monthly air temperature in ºC, average monthly rainfall in mm, along with the geographic coordinates for later georeferencing.

In that preliminary phase of the study, 333 locations, scattered across the entire territory, were analysed.

The water balance for quantification and estimate of water availability in the soil and to indicate water deficit and surplus was developed using the methodology proposed by Thornthwaite and Mather (1955) using the software developed by Brunini and Caputi (2001).

In this case, the average monthly values of air temperature and rainfall were entered in the software and the corresponding water balance parameters were created to obtain the following indices:

a) total annual water deficit (mm);

b) water deficit of the crop’s growth season (mm);

c) annual potential evapotranspiration (mm);

d) total annual water surplus (mm).

The scenario of climatic behaviour and water balance in terms of prospects established by IPCC was evaluated taking into account an average annual warming of 2ºC, considering the effect of such an increase in the period of water deficit, in other words, during the dry season, and its intensity (Assad and Pinto, 2008).

With the new scenario of air temperature, these new values are again inserted into the original data set and new water balances are created considering this increase in air temperature. Water balance has the precision as defined in methodology described by Brunini and Caputi (2001) and the major point is to use soil water holding capacity appropriate for the study.

After the development of the agroclimatic charts and the definition of crop demands in terms of temperature and water supply and the combination of these factors, the agroclimatic zoning was
established. Its climatic adaptation regions were those indicated in Table 1 (Brunini et al., 2007; Brunini et al., 2008b; Brunini, 2008; Brunini et al. 2009).

The characteristics used to quantify crop development and weather variables are used for general crop zoning and they are widely used. For sugarcane, the parameters were defined based on the work carried out by Brunini et al. (2007), Brunini et al. (2009), and Camargo and Ortolani (1964).

**Table 1**—Characteristics of climate and crop development conditions.

<table>
<thead>
<tr>
<th>Average annual temperature (ºC)</th>
<th>Classification</th>
<th>Annual water deficit (mm)</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 18</td>
<td>Unsuitable</td>
<td>&lt; 240</td>
<td>Suitable</td>
</tr>
<tr>
<td>18–19</td>
<td>Borderline to unsuitable</td>
<td>240–300</td>
<td>Borderline–Limitations</td>
</tr>
<tr>
<td>19–21</td>
<td>Marginal</td>
<td>300–400</td>
<td>Borderline</td>
</tr>
<tr>
<td>21–26</td>
<td>Suitable</td>
<td>400–600</td>
<td>Borderline–Restrictions</td>
</tr>
<tr>
<td>&gt; 26</td>
<td>Borderline</td>
<td>600–800</td>
<td>Unsuitable–Restrictions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 800</td>
<td>Unsuitable</td>
</tr>
</tbody>
</table>

**Results and discussion**

Based on weather parameters and crop response, the study was sub-divided into 2 major topics, one considering the actual climate scenario and an analysis considering global warming, based on a temperature increase of about 2ºC.

**Actual climate scenario**

Theme climatic maps were developed based on climatic information of the locations; they refer to temperature and water availability for Mexico, according to Figures 1 and 2. The maps were developed with the use of the ArcGis program and the information and data made available in shapefile form, which may be converted to Excel spreadsheets.

![Fig. 1—Average annual air temperature for the Republic of Mexico (preliminary analysis).](image-url)
The edaphological and climatic suitability map of the crop, with the different conditions of adaptation and soil type, was based on the crossing of information from these maps. This information is presented in Figure 3. Basic suitability information for each location and the indication of suitable or unsuitable areas generated the restrictive factors which are specified for each location in each growing stage of the crop, allowing the evaluation of the degree of risk and the most restrictive factor. The basic characteristic for obtaining the results in Figure 3 was the crossing of temperature and water deficit suitability. After this initial process, the information was then compared to the parameters of water balance during the crop growth season, which occurs from September to May, when the climatic restrictions related to water deficit or surplus and effects of temperature in the cycle and productivity are extremely important.
Figure 4 presents the climatic availability conditions in the crop growth season. The climatic restriction is seen in various regions, although in a great part of the regions considered adequate, based on annual climate factor, this situation is reinforced by this more restricted analysis, both in terms of temperature and water availability.

**Fig. 4a**—Preliminary indication of edaphological and climatic suitability for sugarcane crops in the Republic of Mexico, during the crop growth season (temperature restriction).

**Fig. 4b**—Preliminary indication of edaphological and climatic suitability for sugarcane crops in the Republic of Mexico, during the crop growth season (water availability restrictions).

**Climatic changes and crop adaptation**

The aspects of climate change and global warming cannot be viewed based only on a single climatic characteristic, whether it is temperature or rainfall. The processes involved in changes in...
the crop’s response to environmental stress do not depend only on the interaction of plant and environment, but also on the crop’s adaptation processes and metabolic adjustments to the new climatic levels.

Thus, in this study, a simple analogy between a possible global warming scenario is presented considering an average air temperature increase of 2ºC. This anomaly was incorporated in the monthly water balances, and the results of water deficit and surplus were then associated.

Figure 5 presents the comparison of results in terms of water balance when an average of 2ºC was added to the average air temperature for some locations, although the analogy was performed for the 333 locations. It is possible to note that the dry period for the different locations, in other words, its beginning and its end, is practically the same, but the drought intensity, as represented by the total annual water deficit, increases.

These results lead to two different considerations; a) duration of the drought period: in the aspect of annual range of drought period duration, the crop would not be totally affected, indicating that there would be conditions for development and agricultural use; b) intensity of drought: in this case, the varieties would be more exposed to stronger water stress, which could lead to reduction of productivity in sugar, and indicate a greater need for irrigation; and that, in addition to water stress, the low availability of water in the soil would increase the flow of sensitive heat (warming of the air, exposing crops to double stress).

A new scenario indicated by annual water deficit, as shown in Table 2, would be available based on the ratio between the beginning and the end of the drought period, and the intensity of the drought.

Fig. 5—Comparison of the monthly water balance terms for some locations in the Republic of Mexico, for current scenarios and with a 2ºC air temperature increase.
Table 2—Scenario of water deficit climatic characteristics, with a 2°C average air temperature increase, and behaviour of sugarcane crop.

<table>
<thead>
<tr>
<th>Average temperature (ºC)</th>
<th>Classification</th>
<th>Water deficit + 2°C (mm)</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 18</td>
<td>Suitable</td>
<td>&lt; 240</td>
<td>Suitable</td>
</tr>
<tr>
<td>18–19</td>
<td>Borderline to unsuitable</td>
<td>240–300</td>
<td>Suitable–Limitation</td>
</tr>
<tr>
<td>19–21</td>
<td>Borderline</td>
<td>300–400</td>
<td>Borderline–Limitation</td>
</tr>
<tr>
<td>21–26</td>
<td>Suitable</td>
<td>400–600</td>
<td>Unsuitable–Adjustment</td>
</tr>
<tr>
<td>&gt; 26</td>
<td>Borderline</td>
<td>&gt; 600</td>
<td>Unsuitable</td>
</tr>
</tbody>
</table>

This is also reflected by the climatic availability map, concerning growth and stabilisation period of the crop, normally from September to May. The representative maps of annual temperature availability (average temperature) and annual water deficit were redone based on these analyses, as presented in Figures 6 and 7.

Fig. 6—Estimate of average annual air temperature for the Republic of Mexico, with a 2°C linear average air temperature increase (preliminary analysis).

Fig. 7—Estimate of average annual water deficit for the Republic of Mexico with a 2°C linear average air temperature increase (preliminary analysis).
In addition to that, an analysis for the growth period and complete establishment of the crop was made, also with the scenario of a 2°C linear average air temperature increase. The confrontation of these data presents a new dynamic of agricultural use of that crop in Mexico, as shown in the map in Figure 8. These analyses, when compared to water deficit characteristics in the growth season (Figure 9), indicate that a better varietal management and choice of varieties that are more adapted to longer periods of water stress and high night time temperatures should be used.

It is important to mention that these studies are preliminary and that a wider range of data and locations, as well as deeper evaluation of the global warming scenarios, should be incorporated. Moreover, the study of the climatic scenario was based only on warming, with no modification of rainfall pattern.

Fig. 8—Indication of edaphological and climatic suitability for sugarcane crop in the Republic of Mexico, with a 2°C linear average air temperature increase (preliminary analysis)

Fig. 9a—Preliminary indication of edaphological and climatic suitability for sugarcane crop in the Republic of Mexico, during crop growth season, with a 2°C linear increase in the average air temperature (preliminary analysis—temperature restriction).
A previous study made by Brunini et al. (2008a), when comparing recharge of aquifers determined by the difference between rainfall and potential evapotranspiration, indicates that, if the warming is accompanied by an increase in monthly rainfall of at least 20%, there will be a reduction in the total of estimated water deficit, and greater aquifer recharge.

**Conclusions**

The results analysed indicate that, in terms of edaphological and climatic aspects, the Republic of Mexico presents plentiful conditions for the commercial use of the sugarcane crop.

With the incorporation of the global warming factor, of up to 2ºC, the areas indicated as fully adequate for the development of the crop undergo modification in the water restriction aspect and some areas become restrictive due to the high values of average air temperature, above 26ºC, although it does not make commercial use impractical.

Furthermore, the climatic modification study was developed based only on the increase of average annual temperature, not taking into account factors such as: rainfall distribution and total rainfall, increase and/or decrease of frost, and increase in likelihood of drought risks, which may change the scenario presented.

**Acknowledgement**

The authors wish to express their gratitude to the National Weather Service of Mexico for providing weather data at the web site; otherwise the study could not have been performed.

**REFERENCES**


ZONAGE AGROCLIMATIQUE ET RISQUES CLIMATIQUES DE LA CANNE A SUCRE AU MEXIQUE: ETUDE PRELIMINAIRES TENANT COMPTE DE SCENARIOS DE CHANGEMENTS CLIMATIQUES

Par

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MOTS CLES: Canne a Sucre, Zonage de Cultures, Risques Climatiques, Changement Climatique.

Résumé
DANS LES SYSTEMES de culture et climats existants, une nouvelle source d’incertitude doit être prise en compte: les scénarios de température et de disponibilité en eau résultants du changements climatiques. A ce niveau, le zonage agricole, établi à partir du potentiel climatique et édaphique d’une région, des scénarios climatiques et des risques associés, devient indispensable. Ce papier prend en compte un exemple de culture de canne à sucre au Mexique, précise les surfaces de développement possibles de la culture et indique les risques climatiques durant la croissance sur les critères de zonage, ainsi que l’impact du réchauffement climatique dans les futurs scénarios. Le domaine d’application agroclimatique et le zonage édaphique et climatique ont été définis en quantifiant les ressources physiques et les paramètres du bilan hydrique de différentes régions, et en indiquant les relations entre disponibilité en énergie, fourniture en eau et besoin en eau de la culture. De plus, l’étude a déterminé l’influence des changements climatiques sur la quantification du bilan hydrique de ces régions et les effets de ces changements sur le développement de la canne. L’étude a été basée sur des séries historiques de données climatiques accessibles sur le web, provenant des instituts de recherche Mexicains et du département météorologique national de Mexico. Les produits disponibles sont: a) la température de l’air mensuelle et annuelle, b) la pluviométrie totale mensuelle et annuelle, c) les valeurs mensuelles et bimensuelles des déficits et excès d’eau, d) la probabilité mensuelle et bimensuelle de sécheresse ainsi que des cartes de gel. Ainsi, des cartes d’aptabilité agroclimatique des diverses régions du Mexique ont été réalisées en prenant en compte les conditions climatiques actuelles, l’augmentation de conditions climatiques défavorables et les changements de scénarios dus au réchauffement climatique. Les risques climatiques associés aux températures élevées ou basses et la probabilité de sécheresses sont indiqués à la fois pour les facteurs météorologiques et agro météorologiques. Les régions les plus adaptées au développement de cette culture sont également présentées.
ZONIFICACIÓN AGROCLIMÁTICO Y RIESGOS CLIMÁTICOS PARA LA CAÑA DE AZÚCAR EN MÉJICO- UN ESTUDIO PRELIMINAR CONSIDERANDO LAS PERSPECTIVAS DE CAMBIO CLIMÁTICO

Por


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PALABRAS CLAVES: Caña de Azúcar, Zonificación de Cultivos, Riesgos Climáticos, Cambio Climático.

Resumen

EN LA PERSPECTIVA existente de los actuales sistemas de manejo agrícola y estándares climáticos se debe considerar una nueva fuente de incertidumbre a saber: los escenarios térmicos y la disponibilidad de agua como consecuencia de los cambios climáticos. En este aspecto, la zonificación agrícola, basada en el potencial climático- edafológico de una región, y las perspectivas climáticas, junto con los riesgos asociados, resultan altamente relevantes. Este trabajo contempla un ejemplo para el cultivo de caña de azúcar en Méjico, indicando posibles áreas potenciales para el desarrollo del cultivo, y cuales son los riesgos climáticos durante el crecimiento de la planta, basado en criterios de zonificación del cultivo, y también considera el impacto del calentamiento global en las perspectivas futuras. El ámbito agro climático y la zonificación climático-edafológica se definieron mediante la cuantificación de recursos físicos y de parámetros del balance hídrico de diferentes regiones, indicando la relación entre la energía disponible, el suministro hídrico y la demanda de agua del cultivo. Además, el estudio determinó la influencia de los cambios climáticos en la cuantificación del balance hídrico por regiones y los efectos de esta anomalía en el desarrollo de la caña de azúcar. El trabajo se basó en series históricas de datos meteorológicos obtenidos de institutos de investigación de Méjico y del Servicio Meteorológico Nacional de Méjico, accesibles en la Web. Los datos disponibles son: a) temperatura del aire mensual y anual; b) precipitaciones totales mensuales y anuales; c) valores mensuales y quincenales de déficit y excedentes hídricos; d) probabilidad mensual y quincenal de sequías y mapas de heladas. Como resultado se obtuvieron mapas agroclimáticos apropiados para varias regiones en Méjico, considerando los estándares climáticos actuales y también el incremento de las adversidades meteorológicas y el cambio en las perspectivas debido al calentamiento global. Los riesgos climáticos asociados con altas o bajas temperaturas y la probabilidad de sequías fueron demostrados para factores agrometeorológicos y meteorológicos, con una indicación de las regiones que son más adecuadas para el desarrollo de este cultivo.
IMPACT OF HIGH RATES OF COAL FLYASH ON SOME PERTINENT SOIL CHARACTERISTICS AND SUGARCANE YIELD IN MAURITIUS

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KEYWORDS: Wastes, Cogeneration, Nutrients, Heavy Metals, Uptake.

Abstract

The combustion of coal for cogeneration of electricity by the sugarcane industry in Mauritius generates annually some 20 000 tonnes of ash that need to be disposed of in an environmentally sound manner. As large scale application of ash has been reported to impart agronomic benefits but data under conditions prevailing in Mauritius are lacking, the impact of disposing 50 to 100 t/ha coal flyash in sugarcane fields on soil quality and on sugarcane production was studied in field trials at Belle Rive (>3500 mm/y rainfall), Union Park (>3000 mm/y rainfall), Pamplemousses (>1500 mm/y rainfall) and Médine (900 mm/y rainfall). Though coal ash did not affect soil pH, soil salinity and even soil exchangeable bases, its application at 100 t/ha, when compared to mineral fertilizers, resulted in a reduction of sugar yield at three sites by an average of 1.18 t sugar/ha. At the lower rate of 50 t/ha coal ash, in spite of a significant yield decrease observed at Belle Rive, sugarcane production at Pamplemousses, Union Park and Médine was not significantly different from the control. The N and K uptake by sugarcane was not influenced by the coal ash, though P uptake was enhanced on account of the supplementary P provided in the ash. Additionally, because of its low heavy metal content, coal ash did not increase the heavy metal uptake by the sugarcane plant. In view of the adverse effects observed on sugarcane production, the disposal of rates of coal ash as high as 100 t/ha in sugarcane lands should not be contemplated.

Introduction

In Mauritius, sugarcane is cultivated on some 69 000 ha which represents 85% of the arable land in the country.

The average annual production of five million tonnes cane is currently processed by seven sugar mills to produce on average 500 000 tonnes sugar and 1.5 million tonnes of bagasse.

Through the combustion of bagasse during the crop season, and that of 440 000 tonnes coal during the intercrop season, the sugarcane industry exports some 1300 GWh of electricity to the national grid, representing around 60% of the country’s need. However, cogeneration with coal generates around 20 000 tonnes coal ashes which have to be disposed of judiciously.

Various means of disposal of the ash exist. For example, ash is useful as a construction material or it can be used to decontaminate effluents, but the application of coal ash to agricultural land is believed to represent the most sensible option from both the economic and environment points of view.

Coal ash is in fact a finely divided, amorphous ferro-alumino silicate material, containing all the essential elements that occur naturally in soil except humus and nitrogen (Sear et al., 2003).

It has a pH around 9–10 and possesses certain physical and chemical properties that can be useful, for example, to neutralise soil acidity (Stevens and Dunn, 2004).

Ash has thus been used as a soil amendment (Adriano et al., 2002) and as a source of plant nutrients (Wong and Wong, 1986). Studies on the effects of coal ash on sugarcane yield, however,
remain scanty. Since 20 000 tonnes of coal ash need to be disposed of every year by the sugarcane industry in Mauritius, a study was initiated to assess (i) their impact on soil chemical properties and (ii) their effect on sugarcane yield when high rates are applied.

Materials and methods

Field experiments

Field trials were laid down in four different agro climatic regions of Mauritius, namely at Belle Rive on a Dystropeptic Gibbsiorthox receiving more than 3500 mm of rain per year, at Union Park on a Lithic Humitropept with an annual rainfall of 3300 mm, at Pamplemousses on an Oxic Humitropept receiving 1500 mm rain per year and at Médine, on an Ustic Eutropept with less than 1000 mm rain per year. Some relevant characteristics of the soils at the four experimental sites are shown in Table 1.

Coal ash was applied before planting at two rates (50 and 100 t/ha on a fresh weight basis, 66.42% dry matter). The control treatment received only N and K fertilizers at rates recommended for sugarcane (145 kg N/ha and 190 kg K₂O/ha).

No P fertilisation was applied as soil tests indicated sufficiency in P at all four sites. The N level in the two coal ash treatments was adjusted to the recommended rate of 145 kg N/ha using urea.

All treatments were replicated four times in a randomised complete block design at each experimental site and each treatment plot consisted of four 10 metre rows of sugarcane spaced 1.5 m apart.

Sugarcane was planted at the four sites using three bud cuttings and the resulting plant cane crop was harvested 12 months later in July 2006. The first and second ratoons were harvested in the month of August 2007 and 2008 respectively.

At harvest every year, the cane stalks from the two central rows of each plot were weighed to obtain the cane yields and then sampled for determination of sucrose content with an automatic saccharimeter.

The uptake of NPK and heavy metals (Cu, Zn, Ni, Mn, Pb, and Hg) in the different parts of the cane plant (stalk, top and trash) were measured for the plant cane crop. The NPK in the different plant parts was determined according to the method described by McDonald (1978) while heavy metals were analysed as outlined by Novozamsky et al. (1986).
Results and discussion

Elemental composition of coal ash

The mean elemental composition of the coal flyash collected every three months over a period of three years at three different power stations is shown in Table 2.

As expected, as shown by the range of values obtained, a great variability existed in the elemental characteristics of the coal ash. As reported by Adriano et al, (1980), the chemical composition of ash depends on the source of coal, combustion conditions in the power station and the type of emission control devices used.

Coal ash has an alkaline pH ranging between 7.5 and 11.5 and contains significant amounts of P and K which are essential plant nutrients. The exchangeable calcium which may be as high as 66.1 cmol+/kg in coal ash is responsible for its alkaline nature.

The concentrations of heavy metals obtained in coal ash are, on the other hand, generally much lower than the United States Environmental Protection Agency (USEPA) ceiling limits for wastes (Zn: 420 mg/kg, Ni: 7500 mg/kg, Cu: 4300 mg/kg, Pb: 840 mg/kg, Cd: 85 mg/kg and Hg: 57 mg/kg), (USEPA, 1992).

Specifically the elemental composition of coal ash applied at planting was 1.1 g N/kg, 2.7 g P/kg and 2.2 g K/kg. The composition of coal ash analysed in this study in fact concurs with that reported by Carlson and Adriano (1993) who found that ash in general is quite high in plant nutrients except for N which is lost by volatilisation during combustion.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Coal ash</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td></td>
<td>9.4</td>
<td>7.5–11.5</td>
</tr>
<tr>
<td>Electrical</td>
<td>mS/cm</td>
<td>3.6</td>
<td>1.8–5.7</td>
</tr>
<tr>
<td>conductivity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exchangeable Ca</td>
<td>cmol+/kg</td>
<td>32.7</td>
<td>3.5–66.1</td>
</tr>
<tr>
<td>Exchangeable K</td>
<td>cmol+/kg</td>
<td>7.6</td>
<td>0.2–21.4</td>
</tr>
<tr>
<td>Exchangeable Mg</td>
<td></td>
<td>8.1</td>
<td>1.8–17.2</td>
</tr>
<tr>
<td>Total N</td>
<td>g/kg</td>
<td>1.9</td>
<td>0.7–5.9</td>
</tr>
<tr>
<td>Total P</td>
<td>g/kg</td>
<td>5.1</td>
<td>3.9–6.8</td>
</tr>
<tr>
<td>Total K</td>
<td>g/kg</td>
<td>6.2</td>
<td>1.9–14.2</td>
</tr>
<tr>
<td>Si</td>
<td></td>
<td>4.3</td>
<td>2.1–9.7</td>
</tr>
<tr>
<td>Fe</td>
<td></td>
<td>20.8</td>
<td>8.1–46.7</td>
</tr>
<tr>
<td>Mn</td>
<td></td>
<td>0.6</td>
<td>0.03–0.8</td>
</tr>
<tr>
<td>Zn</td>
<td>mg/kg</td>
<td>93.7</td>
<td>1.0–381.4</td>
</tr>
<tr>
<td>Ni</td>
<td></td>
<td>53.2</td>
<td>10.1–109.8</td>
</tr>
<tr>
<td>Cu</td>
<td>mg/kg</td>
<td>59.5</td>
<td>20.9–132.8</td>
</tr>
<tr>
<td>Pb</td>
<td>mg/kg</td>
<td>51.9</td>
<td>2.0–144.4</td>
</tr>
<tr>
<td>Cd</td>
<td>mg/kg</td>
<td>0.5</td>
<td>0.2–0.9</td>
</tr>
<tr>
<td>Hg</td>
<td></td>
<td>1.1</td>
<td>0.01–8.8</td>
</tr>
</tbody>
</table>
Coal ash used in this study has also been found to have non-detectable levels of polyaromatic hydrocarbons and polychlorinated biphenyls (GC MSD detection limits 0.02 mg/kg), probably due to the high combustion temperatures which had caused these organic compounds to be degraded. However, as reviewed by Reijnders (2005), coal ashes can also contain quite significant amounts of persistent organic compounds.

**Effect of coal ash on soil pH**

The results obtained in this study showed no major changes in soil pH even after the addition of 100 t/ha coal ash (Table 3). The inherent buffering capacity of soils has probably resisted the changes in pH. In view of the high rates of coal flyash that would be needed to raise significantly the soil pH, coal ash would therefore not be economically viable as an amendment to correct soil acidity in the soils of Mauritius. This finding is in agreement with that reported by Sikka and Kansal (1994) who have also observed no change in soil pH following application of high rates of flyash.

<table>
<thead>
<tr>
<th>Application</th>
<th>NPK fertilizers</th>
<th>100 t/ha coal ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before</td>
<td>5.14 ± 0.10</td>
<td>5.14 ± 0.10</td>
</tr>
<tr>
<td>One month after</td>
<td>5.33 ± 0.30</td>
<td>5.42 ± 0.07</td>
</tr>
<tr>
<td>12 months after</td>
<td>5.33 ± 0.08</td>
<td>5.46 ± 0.22</td>
</tr>
<tr>
<td>24 months after</td>
<td>5.36 ± 0.02</td>
<td>5.73 ± 0.10</td>
</tr>
</tbody>
</table>

In fact as explained by Cline *et al.*, (2000), the poor liming effect of coal ash is due in part to the low amount of mineralogical lime since a significant portion of its CaO is present in the vitreous components of the ash and is generally released very slowly.

**Effect of coal ash on soil electrical conductivity**

Soil salinity, as reflected by soil electrical conductivity, increased substantially one month after the application of 100 t/ha coal ash (Table 4). But after 12 and even 24 months, the soil electrical conductivity had returned close to its original value of 81.2 µS/cm. Even with the increase in electrical conductivity of the soil observed after one month, the electrical conductivity remained much lower than the maximum value of 1700 µS/cm that sugarcane can tolerate (Rhoades and Loveday, 1990).

It has been reported that the decrease in soil electrical conductivity with time is the result of weathering processes of the coal ash such as hydration and carbonation which play important roles in transforming the primary minerals in coal ash such as CaO and MgO into less reactive secondary mineralogical products that contribute little towards raising soil salinity (Adriano *et al.*, 1980).

<table>
<thead>
<tr>
<th>Application</th>
<th>NPK fertilizers</th>
<th>100 t/ha coal ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before</td>
<td>81.2 ± 29.9</td>
<td>81.2 ± 29.9</td>
</tr>
<tr>
<td>One month after</td>
<td>125.4 ± 40.6</td>
<td>166.8 ± 33.9</td>
</tr>
<tr>
<td>12 months after</td>
<td>49.4 ± 8.1</td>
<td>83.1 ± 23.5</td>
</tr>
<tr>
<td>24 months after</td>
<td>49.5 ± 5.3</td>
<td>63.5 ± 12.9</td>
</tr>
</tbody>
</table>
Effect of coal ash on soil exchangeable bases

Based on its K content, the application of 100 t/ha of coal ash supplied 220 kg K/ha or 265 kg K$_2$O/ha as opposed to 190 kg K$_2$O/ha in the control treatment where only mineral fertilizers were used. This higher rate of K from coal ash had been insufficient to significantly raise the exchangeable K in the soils. Indeed, soil exchangeable K one month after application of 100 t/ha at all sites was similar to that obtained when 320 kg muriate of potash was used. Likewise, the amounts of Na (17 kg Na/ha) and Mg (97 kg Mg/ha) added to the soil by coal ash applied at 100 t/ha did not significantly increase exchangeable Na and Mg in soil as compared to mineral fertilizers. On the other hand, the addition of 654 kg Ca/ha that the soils received from 100 t/ha coal ash did raise soil exchangeable Ca in the soil (Table 5), particularly one month after application, but this increase still remained within the limits of the standard error (SE).

<table>
<thead>
<tr>
<th>Application</th>
<th>NPK fertilizers</th>
<th>100 t/ha coal ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exchangeable Ca</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>4.78 ± 0.8</td>
<td>4.78 ± 0.8</td>
</tr>
<tr>
<td>One month after</td>
<td>4.73 ± 1.7</td>
<td>5.90 ± 1.7</td>
</tr>
<tr>
<td>12 months after</td>
<td>3.18 ± 1.2</td>
<td>4.78 ± 1.4</td>
</tr>
<tr>
<td>24 months after</td>
<td>3.41 ± 1.5</td>
<td>4.09 ± 0.9</td>
</tr>
</tbody>
</table>

Cane and sugar yields

Cane and sugar yields in the study followed the same pattern as shown in Figure 1. The addition of coal ash at 100 t/ha decreased cane and sugar yields when compared to the control treatment except at the experimental site of Médine, where no significant difference was found among the treatments.

The application of 50 t/ha of coal ash on the other hand did not in general result in lower yields when compared with mineral fertilizers. At Union Park, a significant increase in sugar yield was even obtained with this lower rate of coal ash. However, certain soils such as at Belle Rive would not tolerate the application of as low as 50 t/ha coal ash as evidenced by the decrease in cane and sugar yields obtained.

The findings of the present study confirmed that, with ash at high dosage, such conclusions as those reported by Siddiqui and Singh (2005) that ash would increase yields of crops such as wheat, barley, soybeans and rice, because of the rich content of essential plant nutrients it contains, would not necessarily be true.

In the present study, though the coal ash applied contained appreciable amounts of plant nutrients in particular P (Table 2), a negative impact was observed on sugarcane yield at 100 t/ha. This detrimental effect of coal ash on yield cannot be attributed to a single factor, but rather to a combination of many factors both in the soil and plant systems. In fact, Jala and Goyal (2006) concluded that in general crop response to coal ash is influenced by the physical and chemical characteristics of the soil and also by the crop itself.

Detrimental effects of high rates of coal ash when observed on plant growth were attributed by Singh and Yunus (2000) to a shift in the chemical conditions of the soil due to the highly alkaline pH and the high levels of soluble elements released from the coal ash.

As shown by the pH and electrical conductivity data in Tables 3 and 4, there was no major increase in soil pH and electrical conductivity 12 months after the application of 100 t/ha of coal ash. This implied that, if the detrimental effect of 100 t/ha of coal ash on sugarcane yields as shown in Figure 1 were indeed caused by a change in the chemical environment of the soil, that change cannot be attributed to the high levels of soluble elements in the coal ash.
NPK uptake

There was no significant difference in the uptake of N and K by the cane plant when coal ash at 100 t/ha was compared with mineral fertilizers. The lack of any difference in N uptake was expected as the amount of N applied was the same for all treatments.

The data nevertheless showed that N in the coal ash was just as available as the N in the mineral fertilizers.

The absence of any difference in K uptake on the other hand confirmed that the additional 75 kg K₂O/ha supplied by the 100 t/ha coal ash has been so diluted in the large volume of soil constituting one hectare, that with no significant difference in soil exchangeable K discerned as reported above, no difference in K availability could be perceived by the sugarcane crop when compared to mineral fertilizers.
In general, P uptake was higher with coal ash at 100 and even at 50 t/ha. This was to be expected because no mineral P was added to the control treatment while coal ash at 100 t/ha supplied an additional 270 kg P/ha.

Moreover, as reported by Lee et al. (2008) silicate released from coal ash enhanced the availability of soil phosphate by displacing P from ligand exchange sites thus rendering P more available to be taken up by sugarcane plants.

Furthermore, it has also been reported by the same authors that phosphate sorption decreased in the presence of silicate which caused P to remain in a more available state. The higher availability of the P as translated by the increased uptake of P with coal ash by sugarcane was, however, not reflected in sugarcane yield (Figure 1) indicating that P was not a limiting nutrient to growth.

**Heavy metal uptake**

There was no significant difference in the uptake of the different heavy metals by the plant cane at the four different sites. The concentrations of heavy metals (Cu, Zn, Ni, Mn, Pb and Hg) in the aboveground parts of the cane crop (stalk, top and trash), 12 months after the application of coal ash at 50 and 100 t/ha, remained low and were not significantly different from the concentrations found in the sugarcane plants that received only mineral fertilizer.

This lack of difference in uptake can be explained by the fact that these heavy metals are large cations which are not very mobile in soil. Other studies have attributed the low uptake of heavy metals by crops as being due to a reduced mobility of heavy metals in an alkaline medium brought about in the vicinity by the ash and by an increase in the sorption of these heavy metals in soil (Ram et al., 2007).

**Conclusion**

Though high rates of coal ash will have little impact on the soil chemical properties as reflected by soil pH, soil salinity and soil exchangeable bases, the present study showed that disposal of coal ash at rates of 100 t/ha should not be entertained in soils under sugarcane in Mauritius. Though the heavy metals present in the coal ash will pose little concern since their
uptake by sugarcane will be little affected, the shift in the chemical conditions in the soil brought about by ash will in general lead to a decline in sugarcane production in Mauritius.

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IMPACT DE FORTES DOSES DE CENDRE DE CHARBON SUR CERTAINES CARACTERISTIQUES DU SOL ET SUR LE RENDEMENT DE LA CANNE À SUCRE

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MOTS-CLES: Déchets, Cogénération, Éléments Nutritifs, Métaux Lourds, Prélèvement.

Résumé
LA COMBUSTION de charbon pour produire l'électricité par l'industrie sucrière à Maurice génère annuellement quelque 20 000 tonnes de cendres qui doivent être éliminées d'une manière écologiquement rationnelle. Il a été rapporté que l'application à grande échelle de cendres présente des avantages agronomiques; cependant les données dans des conditions prévalant à Maurice n'étant pas disponibles, l'impact de l'élimination de 50 à 100 t/ha de cendres de charbon dans les champs de canne à sucre sur la qualité des sols et le rendement de la canne à sucre a été étudié dans des essais implantés dans quatre sites aux conditions agroclimatiques différentes, notamment à Belle-Rive (>3500 mm de pluie/an), Union Park (>3000 mm de pluie/an), Pamplemousses (> 1500 mm de pluie/an et Médine (pluie 900 mm de pluie/an). Bien que la cendre de charbon n'a pas eu d'incidence sur le pH, la salinité et même les bases échangeables du sol, son application à 100 t/ha par rapport aux engrais minéraux, a entraîné une réduction du rendement en sucre d'environ 1.18 t/ha dans trois des essais. Au taux inférieur de 50 t/ha de cendre de charbon, en dépit d'une baisse significative des rendements observés à Belle Rive, la production de canne à Pamplemousses, Union Park et Médine n'a pas été significativement différente de celle du contrôle. L’absorption de N et de K par la canne à sucre n'a pas été influencée par la cendre de charbon, bien que celle de P a été renforcée en raison d’un apport supplémentaire de P provenant des cendres de charbon. De plus en raison de sa faible teneur en métaux lourds, la cendre de charbon n'a pas augmenté l'absorption de métaux lourds par la canne à sucre. Compte tenu des effets indésirables observés sur la production de canne à sucre, l'élimination de la cendre de charbon à des taux aussi élevés que 100 t/ha dans les champs de canne à sucre ne devrait pas être envisagé.
IMPACTO DE ALTAS CANTIDADES DE MATERIAL PARTICULADO DE CHIMENEAS EN ALGUNAS CARACTERÍSTICAS DEL SUELO Y EN LOS RENDIMIENTOS DE LA CAÑA DE AZÚCAR EN MAURITIUS

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PALABRAS CLAVE: Residuos, Cogeneración, Nutrientes, Metales Pesados, Captación.

Resumen

LA COMBUSTIÓN de carbón para la cogeneración de electricidad por parte de la industria azucarera en Mauricio genera anualmente unas 20 000 toneladas de material particulado de chimeneas que deben ser eliminados de manera ambientalmente racional. Se han reportado beneficios agronómicos de la aplicación a gran escala de ceniza, pero la información para las condiciones que prevalecen en Mauricio es escasa. El impacto de la aplicación de 50 a 100 t/ha de material particulado sobre la calidad del suelo y en la producción de caña de azúcar, ha sido evaluado en ensayos a campo realizados en Belle Rive (lluvia>3500 mm/año), Union Park (lluvia>3000 mm/año), Pamplemousses (lluvia>1500 mm/año) y Médine (900 mm de lluvia mm/año). A pesar de que las cenizas de carbón no afecta el pH del suelo, la salinidad del suelo, ni las bases intercambiables, aplicaciones de 100 t/ha, en comparación a aplicaciones de abonos minerales, se tradujo en una reducción promedio del rendimiento de azúcar, de 1.18 t/ha, en tres sitios. La dosis más baja de 50 t/ha de cenizas produjo un descenso significativo de los rendimientos en Belle Rive, mientras que la producción de caña de azúcar en Pamplemousses, Union Park y Médine no fue significativamente diferente del testigo. La absorción de N y K por parte de la caña de azúcar no se vio afectada por el material particulado, a pesar de que la absorción de P fue mayor a causa de los P complementarios provistos por la ceniza. Además, debido a su bajo contenido de metales pesados, el material particulado no aumentó la captación de metales pesados por parte de la planta de caña de azúcar. En vista de los efectos adversos observados en la producción de caña de azúcar, la disposición de cantidades de cenizas de carbón, tan altas como 100 t/ha no deben ser contempladas en campos cañeros.
MODIFIED DUAL ROW PLANTING SYSTEM FOR GREEN CANE MANAGEMENT IN THE TROPICS

By

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KEYWORDS: Row Spacing, Sugar and Cane Yields, Control Traffic.

Abstract

AFTER GREEN cane harvesting in high yielding fields, a large amount of residues are left on the soil surface which interfere with the standard cropping practices, normally in burnt fields. A new planting system arrangement has been tested to reduce cane stool damage, soil compaction, cost of residue handling, allelopathic effects, herbicide use, and to improve irrigation efficiency. The so-called modified dual row planting (MDRP) allows for controlled traffic paths of 3.9 m wide followed by a set of three dual rows of cane at 0.8 m between rows and 2.1 m in between two adjacent pairs of dual rows. Total furrow length per hectare is equivalent to a single-row planting at 1.75 m spacing (5714 m of cane row/ha). The 3.9 m strip opens enough space to place the residues during manual cutting and leave the cane rows free of residues. The traffic of wagons loaded with cane is conducted on top of the green trash which later decomposes to enrich these areas with organic matter. During development of the plant cane, other crops can be planted to benefit from these open spaces. The MDRP, tested under different soil and climatic conditions, was found to produce a lower cane yield (10 to 20 t/ha) in plant cane as compared to the single-row planting spacing at 1.75 m spacing. After the harvest of the plant and several ratoons, the benefits of the MDRP, due to controlled traffic and less compaction, resulted in a more stable cane production; the cumulative cane production after four cropping cycles showed a higher cane production than the single-row planting. The MDRP also allows for a good separation of the cane windrows from the trash swaths which results in at least 1% higher sugar recovery.

Introduction

The use of large farm machinery for sugarcane cultivation and harvesting has resulted in higher efficiencies at the expense of sound agronomic practices and crop sustainability (Torres and Rodríguez, 1996; Bull et al., 2001). Direct cane stool damage by cane loader and infield transport equipment was more important than compaction itself in determining cane yield of the following ratoon crop (Torres and Villegas, 1993). Later on, Torres and Pantoja (2005) reported that, under wet conditions, controlled traffic of the mechanical harvesting system resulted in similar cane yields as the plots without infield traffic. Therefore, they advised that traffic of infield machinery should be controlled to sustain production in any harvesting system under the conditions of the Cauca Valley in Colombia.

In Australia, Bull and Bull (1996 and 2000) presented a new planting system with dual, triple and quad rows. Row spacing was reduced from 1.5 m to 0.5 m resulting in a linear increase in cane yield of up to 60 t/ha. This system has management limitations due to lack of machinery to fit the narrow spacing. All three farming systems have in common the adoption of strip traffic lanes between the set of cane rows where the soil remains compacted, and no ripping is executed within this area to accommodate machinery traffic. The area between the set of cane rows corresponds to
minimum tillage zones where the soil remains uncompacted promoting soil health. Therefore, new planting systems with dual, triple and quad rows were proposed to improve soil structure. The three high density farming systems outlined by Bull et al. (2001) involved the use of controlled traffic zones, minimum tillage and precision planting.

Harvesting of sugarcane during rainy periods is a common practice that creates problems in the succeeding crop. The use of large capacity wagons with high flotation tyres has not been sufficient to reduce the field problems of compaction and direct crop damage. Matching infield machinery tracks to fit inter-row spacing is required to reduce direct cane stool damage and to limit compaction to the inter-row.

The Colombian sugar industry has been shifting from 1.5 m row spacing to new plantings at 1.65 m and 1.75 m. These spacings open more room to accommodate the large amount of green cane residues in the inter-row after trash lining and, at the same time, look for a better fit to the track widths of the existing infield machinery.

Torres and Rodriguez (1996) presented a review paper describing the forces acting on the soil during the compaction process and compiled a list of the most desirable management practices to minimise, offset or eliminate soil compaction. In general, infield machinery should be lighter, be mounted on high flotation tyres, track widths should match row spacing, and controlled traffic paths should be implemented to reduce stool damage.

In order to adopt most of the well known recommendations to reduce soil degradation, eliminate stool damage, improve fertiliser use efficiency, decrease the need for herbicides, increase irrigation efficiency and minimise the extra cost for green cane residue handling, a new farming system, so-called modified dual row planting system (MDRP) is under experimentation in the Cauca Valley of Colombia.

**Materials and methods**

Within the Colombian sugar industry, infield machinery varies in size, weight and track widths, so it is almost impossible to select a single-row spacing that can eliminate compaction or cane stool damage while opening enough inter-row space to accommodate cane residues to reduce allelopathic effects on ratoon regrowth. The new planting system corresponds to a modification of the conventional dual-row planting where a set of two rows of cane is planted at a distance that varies between 0.3 m to 1.0 m apart and a fixed distance (1.3 to 1.8 m) is kept to separate the centres of dual rows.

Using computer graphic aids, different row-spacing arrangements and infield machinery track widths were plotted to select the best row spacing that could help to achieve the objectives of the system. No single-row spacing was identified to suit the traffic of infield equipment.

Therefore, it was necessary to favour the establishment of a dedicated traffic strip where any infield machinery track width could be accommodated without running over the nearest cane row (Figure 1). The so-called Modified Dual Row Planting has a traffic strip width of 3.9 m and three dual rows of cane at 0.8 m apart and 2.1 m in between two adjacent pairs of dual rows.

Planting of the cane using the new configuration required modification of the furrow opener and the use of surveying equipment to mark the row direction and the spacing between dual rows. The new system was initially planted in a small area at Cenicaña’s experiment station and later on was presented at a cane grower meeting.

The new idea seemed so interesting that a few months later (in 2003), the planted area amounted to 424 ha. Growers at Cenicaña were worried that a new idea that had not been fully proven experimentally was at a high risk.

Fertilisation of the cane row was executed at 50 days after planting as it was necessary to adjust the position of the chisels and hose outlets of the fertiliser box to apply half of the fertiliser dosage on each side of the cane rows.
In order to avoid the convergence of the dual rows into a single row of cane due to intensive cane tillering at such a close spacing (0.8 m), a small duck foot cultivator blade was run over the centre of the dual rows during a hilling up operation. At the same time, the inter row between the dual rows was ready for furrow irrigation. The surface area that comes in contact with the irrigation water is reduced to 25% of the planted area, leaving room for more storage of rainfall water. When a newly planted field under conventional single row spacing is surface-irrigated, the applied volume of water normally amounts to 2500 m$^3$/ha while the irrigation of the MDRP consumed only 500 m$^3$/ha of water increasing the water use efficiency.

The new MDRP planting system has been evaluated and compared to planting at either 1.65 m or 1.75 m spacing at commercial scale under different soil types and climatic conditions using cane varieties CC 85-92, CC 84-75, CC 93-744, CC 92-2198, CC 93-7510 and MZC 84-04.

**Results and discussions**

**Furrow irrigation**

The inter-row between the pair of cane rows was shaped to obtain a parabolic furrow able to carry up to 8 litres per second (L/s) of water. The furrow irrigation system was evaluated at the Mayaguez sugar mill using furrow discharge rates of 4, 5 and 6 L/s applied to the single-row planting at 1.75 m and to the MDRP. As the discharge rate increased, the amount of water applied to MDRP decreased from 1160 m$^3$/ha with 4 L/s to 600 m$^3$/ha with a flow rate of 6 L/s due to a shorter advance time of the water while the volume of water applied to the 1.75 m spacing varied between 1540 m$^3$/ha (4 L/s) and 1250 m$^3$/ha (6 L/s). In terms of depth of water applied to the soil, using a discharge rate of 6 L/s in MDRP resulted in 90 mm of water while, at 1.75 m spacing using the same discharge rate, the applied water depth was equivalent to 125 mm. It is necessary to consider that rainfall events in the tropics can occur at any time; therefore, it would be advantageous to leave some storage capacity in the soil for those rainfalls.

**Cane and sugar yields**

The cane yield and sugar recovery of the plant cane crops were used to calculate the sugar yields which are presented in Figure 2 as isoproduction curves. At a first glance, three cane
productivity groups could be identified as a function of the row spacing. The highest cane yield group consisted of plantings made at 1.65 m spacing with cane yields above 170 t/ha and sucrose content (IRSC) of 11.5%. A second group consisted of plantings at 1.75 m with cane yields between 140 and 170 t/ha and sucrose content below 11.5%.

A third productivity group included the MDRP which showed a great dispersion in cane yields varying from 80 to 150 t/ha due to the lack of sufficient plant population per unit area and because of the effects of soil, climate and cane varieties planted.

In general, a cane yield difference of 20 to 25 t/ha in favour of the single-row plantings at either 1.65 m or 1.75 m was registered. At the same time, the MDRP showed a tendency to form a cluster with high sucrose content above 11.5% as a result of the cleaner cane sent to the factory.

The big differences in cane yield between the plant cane of the new planting system and the single-row plantings caused dissatisfaction and aversion of the cane growers to continue evaluating the new system. A remedial action was taken by Cenicaña and new plantings were conducted at CIAT’s experiment station and the Pichichi sugar estate to test new options to improve the cane yield of the MDRP.

The wide open strips of 3.90 m by 120 m long, intended to accommodate the residues and be a dedicated area for the traffic of the cane wagons, occupy an area of 0.37 ha (37%) which is quite large and has a definite impact on cane yield. A hypothesis emerged to upgrade the cane yield of the new system (Figure 3).

If the reduced population density was the cause of the lower cane yield of this system, it would be necessary to increase the density by planting one or two extra rows of cane in the centre of the 3.9 m strip that may result in a cane yield of the MDRP as high as the ones from the single-row spacing.

After the harvest of the plant cane, the extra rows of cane could be discarded to merge into the MDRP system. It is expected that after harvesting the plant cane all the benefits of the system, such as controlled traffic zones, reduced compaction and stool damage would accrue to sustain a higher cane yield during the following ratoon crops with the possibility that the crop would last longer.
The proposed hypothesis was tested at CIAT’s experiment station by planting one extra row in the MDRP (Figure 4). After three consecutive crops, the cumulative cane production of the MDRP system amounted to 468 t/ha while the cane production at 1.75 m was 459 t/ha, which agrees quite well with the hypothesis. It was clear that, after harvest of the plant cane, the benefits of the system allow for a more stable cane yield, and the crop is expected to last for more ratoons. In addition to the benefits of a more sustainable cane production, an economic analysis including the cost of water, labour savings, reduced use of herbicides and soil improvement due to build-up of organic matter in the wide strips would be necessary.
wagons loaded with cane. The grab loader runs in the 2.1 m space that separates two pairs of adjacent dual rows, without causing serious compaction or stool damage.

The continual addition of residues after three crops of cane to the traffic strips on a clay soil (Vertisol) that was previously used as grazing land has resulted in a build up of soil organic matter. The organic matter content on the 2.1 m spacing that separates the dual row was 3.9% from 0 to 20 cm and 3.35% from 20 to 40 cm depth in the soil profile while, in the traffic strip where there is accumulation of residues, the organic matter content increased to 5.4% from 0 to 20 cm and to 3.4% from 20 to 40 cm depth.

Conclusions

We strongly believe that the MDRP system is a good option to manage cane in a sustainable way, to reduce compaction and stool damage problems, reduce the use of water for irrigation and opens the possibility to intercrop leguminous and other crops such as potatoes, beans or tomatoes. Once the benefits of the system are properly quantified and the temporal differences in cane yield in relation to the single-row planting spacing are accepted or compensated with the planting of one or two extra rows of cane, the adoption of this system may become a reality.

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plantation en double-rang modifiée (MDRP) tient compte des chemins de roulement de 3.9m de large comprenant entre eux 3 lignes jumelées de 0.8m entre rangs et 2.1m entre paires de rangs. La longueur totale de sillons par hectare est équivalente à une plantation en rang simple de 1.75 m d’écartement (5714 m/ha). Les allées de 3.9 m de large laissent assez d’espace pour les résidus provenant de la coupe manuelle et laisse les lignes de cannes sans résidus. Le passage des remorques chargées de canne s’effectue sur les résidus verts qui se décomposent ensuite pour enrichir le sol en matière organique. Durant le développement de la canne plantée, d’autres cultures peuvent être plantées sur ces allées ouvertes. Le MDRP, testé sous différentes conditions de sol et de climat, a produit un rendement plus faible (10 à 20 t/ha) en canne plantée que le système en rang simple avec un écartent de 1.75 m. Après la récolte de la canne plantée et de plusieurs repousses, le système MDRP, dû à des passages contrôlés et moins de compaction, entraîne une production plus stable; et après 5 cycles, une production cumulée supérieure à celle du système en rangs simples. Le système MDRP a permis aussi une bonne séparation des andains de résidus de canne et a produit ainsi une qualité de sucre extractible supérieure de plus de 1%.

SISTEMA DE PLANTACIÓN EN DOBLE SURCO MODIFICADO PARA MANEJO DE CAÑA VERDE EN LOS TROPICOS

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PALABRA CLAVE: Distanciamiento Entre Surcos, Producción de Azúcar y Caña, Tráfico Controlado.

Resumen

Después de la cosecha en verde en cañaverales de alta producción, queda sobre la superficie del suelo una gran cantidad de residuos que interfieren con las prácticas normales de cultivo en campos quemados. Se evaluó un nuevo sistema de diseño de plantación para reducir el daño a la cepa, la compactación del suelo, el costo del manejo de los residuos, los efectos alelopáticos, el uso de herbicidas y mejorar la eficiencia del riego. El llamado surco doble modificado (MDRP) permite un tránsito controlado por la trocha de 3,9 m de ancho seguida por un conjunto de tres surcos dobles de caña a 0,8 m entre surcos y 2,1 m entre dos pares de surcos dobles adyacentes. La longitud total de surcos de caña que se dispone en una superficie de una hectárea en el nuevo diseño, es equivalente a lo plantado en un diseño de surco simple distanciado a 1,75 m (5714 m de surco/ha). Los 3,9 m de trocha abierta dan suficiente espacio para colocar los residuos que se producen durante la cosecha manual y deja a los surcos de caña libres de residuos. El tránsito de carros cargados con caña se realiza sobre los residuos verdes cuya posterior descomposición enriquece esas áreas con materia orgánica. Durante el desarrollo de la caña planta se pueden plantar otros cultivos, para obtener beneficios en ese espacio. El MDRP, evaluado bajo diferentes suelos y condiciones climáticas, produjo en caña planta una disminución en la producción de caña (10 a 20 t/ha), comparado con la plantación en surco simple espaciados a 1,75 m. Después de la cosecha de la planta y varias socas, los beneficios del MDRP, debidos al tránsito controlado y a la menor compactación, resultaron en una producción de caña más estable y la producción acumulada después de cuatro ciclos mostró mayor producción de caña que en la plantación en surco simple. El MDRP también permite una buena operación de limpieza de la caña que deriva en menores niveles de trash en la materia prima, lo cual resulta en por lo menos 1% más de recuperación de azúcar.
CROTALARIA JUNCEA, CANAVALIA ENSIFORMIS AND MUCUNA SP AS POSSIBLE NITROGEN SOURCES FOR FERTILISATION IN SUGARCANE COMMERCIAL NURSERIES

By

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KEYWORDS: Nitrogen Mineralisation, Green Manuring, Crop Rotation.

Abstract

The objectives of this study were to: a) Evaluate the rotation of “Crotalaria juncea, Canavalia ensiformis and Mucuna sp” and their effect on the production of sugarcane during three sowing times. b) To determine the decomposition of the legume plants, and quantify the contribution of nitrogen of each one to the system. An experiment was carried out in a Mollisol soil of the Finca El Naranjo, located in the low area of the sugar region of Guatemala, evaluating the three species of legumes, on three dates of sowing in the winter, starting with the planting of the legumes on June 6th 2006 and repeating it every 15 days for subsequent dates. In all cases the sugarcane planting was made two months after the planting of the legumes. Two further treatments were included, being the commercial practice without legumes and a control without legumes and without N. Plots of cane with legumes were not fertilised with nitrogen. The experimental design used was randomised complete blocks with three replications. Sowing times were the main plot and the sub-plots were the three species of legumes. In order to quantify the decomposition of the legumes, the methodology used was the same as that used by Resende et al (1999) by the use of degradation bags buried under the plots being evaluated at the 7th, 14th, 21st, 35th, 60th, 75th and 120th day after the incorporation of the legumes. To estimate the decomposition rate, we used the Thomas and Asakawa Model, cited by Resende (2000). The results indicated that all the treatments where the legumes were incorporated exceeded the commercial control in terms of sugarcane seed with Canavalia ensiformis which produced 7.4 TCH more than those which were fertilised. The accumulation of nitrogen from the legumes was between 144 and 349 kg of N/ha during the evaluation period with Crotalaria juncea being the best contributor. The average half time of decomposition for the legumes was similar and varied from 17 to 20 days, while the half time of the nitrogen to be mineralised was 5 to 7 days, with Mucuna sp presenting the lowest average half time of decomposition of residues, and the lowest half time of the nitrogen to be mineralised was the Crotalaria juncea.

Introduction

The Guatemalan sugarcane industry replants annually around 20% of the cultivated area (46 000 ha of 230 000 ha), which means that it should establish 4600 ha of seedbeds for plant supply. These seedbeds are planned over a year in advance and fallowed for 6 to 8 months before
being used, which means that the fields used for such activity are not cropped for about 2 to 4 months, and are covered with weeds and sugarcane volunteers from the previous harvest.

Looking for an agro ecological practice that avoids fallowing, there is an opportunity to rotate three species of legumes aiming to find the best season to rotate them in the fields designated for the commercial propagation of the sugarcane. *Crotalaria juncea*, *Canavalia ensiformis* and the *Mucuna* sp are legumes of fast growth and could contribute up to 275 kg of N/ha (Flores, 2005). In addition, they are species that would improve the soil structure, contribute organic matter, and their cover protects the soil from water and wind erosion.

These species were evaluated to determine their suitability under the conditions of the Finca Naranjo San Diego, and also to measure their contribution in terms of nitrogen to the soil, the mineralisation of the residues, and the increase in the amount of the sugarcane seed compared to traditional methods.

In other sugar agro industries, rotation with legumes has provided benefits in tonnage of cane and seed, and they contribute nitrogen and organic matter to the soil. Resende (2000), in Brazil, evaluated *Crotolaria juncea*, *Canavalia ensiformis* and *Mucuna deeringiana* and determined that these species may fix up to 50% of the total N from the atmosphere for use by the crop.

**Methodology**

Two factors were studied: a) three dates of sowing (of legumes and sugarcane) and three species of legumes. A randomised blocks design with three replications was used. Sowing times were the main plots starting with the first one on June 6th of 2006 and the other two starting 15 and 30 days after. The cane planting was established two months after the legume sowing. Legumes were the sub-plots and they have two controls: one absolute and another fertilised without legumes.

The fertilisation of the sugarcane varied in the treatments depending on presence or absence of a legume crop. In the plots where legumes were planted, the cane did not receive nitrogen. Every plot was fertilised with 60 kg of phosphorus per ha, excepting the absolute control, which did not receive fertilisation. Sixty days after the legume sowing, the experimental units were planted with sugarcane variety CP 72-2086.

To ensure the presence of N₂-fixing micro organism in the legume species to be evaluated, the seeds were inoculated with soil from the seedbeds of *Canavalia ensiformis*. The harvest of legumes was done 60 days after the sowing, where all the materials were cut leaving only the residues scattered on the soil. The residues were incorporated mechanically with skid equipment the day after harvest.

The decomposition of the studied legumes, was determined with the aid of degradation bags like the ones used by Resende *et al.* (1999), burying the samples in the soil. A sample was taken on the 7th, 14th, 21st, 35th, 60th, 75th, 120th day after the burial day. The total amount of nitrogen contained in the samples was determined by the digestion method of Kjeldahl.

To estimate the constant decomposition of the residues, we used the Thomas and Asakawa method cited by Resende (2000): \( Lr/Li = e^{-kt} \), where \( Lr \) = dried biomass of the residues incorporated in the soil \( n \) days after the sowing; \( Li \) = dried biomass of the residues before incorporation (0 days); \( e \) = base of natural logarithms; \( t \) = sample time interval expressed in days, and \( k \) = the rate of the constant of decomposition per day. The value of \( k \), was calculated as the time necessary for the residues to disappear after their incorporation in the soil (\( t/2 \)).

The planting of the sugarcane was made with seed from a semi-commercial seed bed with hydrothermal treatment (Buenaventura, 1990) of the variety CP 72-2086. The planting was made five days after the incorporation of the legume residues. The harvest of the seed of the treatments was made manually with machetes making packages of 30 canes. The harvest was made 7 months after the planting.
The parameters evaluated were the following:

a) for the legumes: weight of green mass, dry weight (kg/ha), nitrogen accumulated in the biomass and also the time of degradation of the residues in the soil;

b) for the cane seed: population of stems (number of stems/ha), diameter of the cane stems in cm and production of cane seeds (TCH).

Data were analysed by the analysis of variance and means were compared by Tukey’s Test.

Results

Weight of seed cane and components of the production

The variance analysis indicated statistically significant effects for the times of sowing and the legumes on weight of seed sugarcane. However, there was no interaction between the two variables.

The averages of the effects of the times of sowing and the legumes for the weight of seed cane, population and diameter of stems appear respectively in Tables 1 and 2.

<p>| Table 1—Average effect of legume species in rotation on the weight of seed cane, population and stem diameter. |</p>
<table>
<thead>
<tr>
<th>Legume rotation – cane</th>
<th>Seed weight (TCH)</th>
<th>Population of stem (No. stems/linear metre)</th>
<th>Stem diameter (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mucuna sp + sugarcane (without N)</td>
<td>71.2 (a)</td>
<td>13 (a)</td>
<td>2.40 (a)</td>
</tr>
<tr>
<td>Crotalaria juncea + sugarcane (without N)</td>
<td>69.4 (ab)</td>
<td>15 (a)</td>
<td>2.32 (a)</td>
</tr>
<tr>
<td>Canavalia ensiformis + sugarcane (without N)</td>
<td>73.9 (a)</td>
<td>14 (a)</td>
<td>2.38 (a)</td>
</tr>
<tr>
<td>Commercial control (only sugarcane with N)</td>
<td>66.6 (ab)</td>
<td>14 (a)</td>
<td>2.27 (a)</td>
</tr>
<tr>
<td>Absolute control (only sugarcane without N)</td>
<td>66.0 (b)</td>
<td>15 (a)</td>
<td>2.24 (a)</td>
</tr>
</tbody>
</table>

CV=7.78

Small letters indicate no significant differences between means according to Tukey test at p = 0.05

In relation to species of legumes in rotation (Table 1) the seed weights were between 66.8 and 73.1 tonnes of cane/ha.

Two of the legumes, on average, exceeded the commercial controls. Increases of 7.3 and 4.6 tonnes of cane / ha were obtained with the rotation of Canavalia ensiformis and Mucuna sp respectively, compared to the commercial control without commercial fertiliser.

<p>| Table 2—Average effect of sowing times on the weight of seed cane, population and stem diameter. |</p>
<table>
<thead>
<tr>
<th>Sowing time</th>
<th>Seed weight (TCH)</th>
<th>Population of stem (No. stems/linear metre)</th>
<th>Stem diameter (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time 1 (Starting on 06–06–06)</td>
<td>68.4 (b)</td>
<td>14 (a)</td>
<td>2.33 (a)</td>
</tr>
<tr>
<td>Time 2 (Starting on 21–06–06)</td>
<td>66.8 (b)</td>
<td>16 (a)</td>
<td>2.36 (a)</td>
</tr>
<tr>
<td>Time 3 (Starting on 06–07–06)</td>
<td>73.1 (a)</td>
<td>14 (a)</td>
<td>2.28 (a)</td>
</tr>
</tbody>
</table>

CV=7.78

Small letters indicate no significant differences between means according to Tukey test at p = 0.05

In relation to the sowing time (Table 2), it is observed that the weight of sugarcane seed varied from 66.8 to 73.1 tonnes of cane/ha, depending on the sowing time. The increased production was achieved when legumes were sown in Time 3, being significantly higher than for the other two times.
**Weight of biomass and nitrogen contribution of legumes**

Tables 3 and 4 show the averages of fresh biomass, total N and N accumulation in biomass, respectively, for the sowing and the species of legumes in rotation.

**Table 3**—Fresh biomass, total N and N accumulation (dry base) in three species of legumes in rotation.

<table>
<thead>
<tr>
<th>Species of legumes in rotation</th>
<th>Aerial biomass weight (t/ha)</th>
<th>Humidity (%)</th>
<th>Content of N (%)</th>
<th>N accumulated in aerial biomass (kg N/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mucuna sp</td>
<td>26.1 (b)</td>
<td>82.90</td>
<td>4.8 (a)</td>
<td>216.6 (b)</td>
</tr>
<tr>
<td>Crotalaria juncea</td>
<td>50.8 (a)</td>
<td>81.20</td>
<td>3.6 (b)</td>
<td>349.1 (a)</td>
</tr>
<tr>
<td>Canavalia ensiformis</td>
<td>22.5 (b)</td>
<td>81.67</td>
<td>3.5 (b)</td>
<td>144.1 (b)</td>
</tr>
<tr>
<td>CV=14.72</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Small letters indicate no significant differences between means according to Tukey test at p = 0.05

In relation to species of legumes (Table 3), it is observed that the species with the highest average yield of biomass and the highest N accumulation was *Crotalaria juncea*. This species reaches a yield of fresh biomass of 50.8 t/ha with 81.2% moisture and accumulates 349 kg N/ha in 60 days, contrasting with the yields obtained with the other two species.

Muchovej (1995) quotes that in Florida, United States, the peanut is capable of providing up to 235 kg of N/ha. In Brazil, it is known that *Crotalaria juncea* incorporates around 180 to 200 kg N/ha. On the other hand, Garside *et al.* (1998) reported on the time of harvest of the sugarcane in 1994–1995 with 4 species of legumes: beans cowpea, mucuna, peanuts and soybeans planted at 3 different times. The results showed that, with soybean, around 310 kg N/ha is incorporated; it was the species with the largest amount of nitrogen incorporated into the soil, while the other 3 species incorporated up to 170 kg of N/ha.

**Table 4**—Fresh biomass, N Content and N accumulation in dry biomass of the three legume species evaluated in the three sowing seasons.

<table>
<thead>
<tr>
<th>Sowing time</th>
<th>Aerial biomass weight (t/ha)</th>
<th>Humidity (%)</th>
<th>Content of N (%)</th>
<th>N accumulated in aerial biomass (kg N/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time 1 (Starting on 06–06–06)</td>
<td>39.3 (a)</td>
<td>89.9</td>
<td>3.6 (a)</td>
<td>136.1 (b)</td>
</tr>
<tr>
<td>Time 2 (Starting on 21–06–06)</td>
<td>29.5 (b)</td>
<td>77.9</td>
<td>3.9 (a)</td>
<td>260.2 (a)</td>
</tr>
<tr>
<td>Time 3 (Starting on 06–07–06)</td>
<td>33.2 (ab)</td>
<td>77.8</td>
<td>4.2 (a)</td>
<td>313.3 (a)</td>
</tr>
<tr>
<td>CV=14.72</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Small letters indicate no significant differences between means according to Tukey test at p = 0.05

Table 4 shows that the highest concentration of total N and increased N accumulation in biomass of the legumes were obtained when sowing was during the first week in July (06–07–06) and decreased as sowing was advanced to the first week of June. During the two later times, the highest amount of N was accumulated in the aerial biomass although, in terms of fresh biomass and more water content, the yield was higher in Time 1 caused mainly by the greater weight of *Crotalaria juncea* at this time.

**Degradation time of legumes residues**

The analysis of variance showed statistically significant effects between sowing time and the legume species in rotation, but not for the interactions between time and legumes. The average of
the constant decomposition per day and average time of degradation of the legume residues per time of planting and legume using the Thomas and Asakawa methodology cited by Resende (2000) are presented in Tables 5 and 6.

Table 5—Time and rate of decomposition of the three legumes evaluated in the study.

<table>
<thead>
<tr>
<th>Species of legumes</th>
<th>Decomposition rate (k)</th>
<th>Average time of biomass decomposition (T_{1/2} days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mucuna sp</td>
<td>0.040 (a)</td>
<td>17 (a)</td>
</tr>
<tr>
<td>Crotalaria juncea</td>
<td>0.046 (a)</td>
<td>20 (a)</td>
</tr>
<tr>
<td>Canavalia ensiformis</td>
<td>0.036 (a)</td>
<td>19 (a)</td>
</tr>
<tr>
<td>CV=35.95</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Small letters indicate no significant differences between means according to Tukey test at p = 0.05

Table 5 shows that the decomposition rates of the legume species varied a little from 0.036 to 0.046, and there were minor variations also in the average time of decomposition from 17 to 20 days (Figure 1). These comparisons are supported by the variance analysis and Tukey test.

In practical terms, the rates of decomposition and the average time of decomposition of the three legume species evaluated were very similar and very fast due to the good conditions of temperature and humidity prevailing in the sugarcane region of Guatemala.

Resende (2000) in Brazil evaluated the decomposition rate and the average time of decomposition of four species of legume, *Crotalaria juncea*, *Crotalaria spectabilis*, *Canavalia ensiformis* and *Mucuna deeringianum*. He found that *Crotalaria juncea* was the legume that presented the slowest degradation with a half time of 46 days for decomposition. The *Crotalaria spectabilis*, *Canavalia ensiformis* and *Mucuna deeringiana* had an average of 22, 42 and 45 days respectively.

Resende (2000) reported that the rate and half time difference between *Crotalaria juncea* and the *Canavalia ensiformis* was 0.001 and 3 days respectively, which were similar to results obtained in this study, 0.001 and 1 day respectively.
In terms of sowing time, it was observed that the daily rate of decomposition varied from 0.028 to 0.053. The highest rate was in Time 1 (first week of June sowing), where residues were degraded in a lower average time (15 days) as shown in Table 2.

The highest rate of decomposition of legumes in Time 1 would be associated with a higher humidity on the soil at this time, due to increased rainfall during the initial test compared with the rainfall of Time 3.

Table 6—Average effect of the time of sowing and time of degradation of 3 legumes.

<table>
<thead>
<tr>
<th>Sowing time</th>
<th>Decomposition rate (k)</th>
<th>Average time of biomass decomposition (T_{1/2} days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time 1 (Starting on 06–06–06)</td>
<td>0.053 (a)</td>
<td>15 (a)</td>
</tr>
<tr>
<td>Time 2 (Starting on 21–06–06)</td>
<td>0.040 (a)</td>
<td>18 (a)</td>
</tr>
<tr>
<td>Time 3 (Starting on 06–07–06)</td>
<td>0.028 (a)</td>
<td>23 (a)</td>
</tr>
<tr>
<td>CV=35.95</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Small letters indicate no significant differences between means according to Tukey test at p = 0.05

The average mineralisation of nitrogen per day and half time per sowing time and legumes are presented in Tables 7 and 8.

Table 7—Rate of mineralisation of nitrogen and average time of decomposition of three legumes evaluated in the study.

<table>
<thead>
<tr>
<th>Species of legumes</th>
<th>Decomposition rate of N (k)</th>
<th>Average time of decomposition (T_{1/2} days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mucuna sp</td>
<td>0.115 (a)</td>
<td>6 (a)</td>
</tr>
<tr>
<td>Crotalaria juncea</td>
<td>0.135 (a)</td>
<td>5 (a)</td>
</tr>
<tr>
<td>Canavalia ensiformis</td>
<td>0.114 (a)</td>
<td>6 (a)</td>
</tr>
<tr>
<td>CV = 16.18</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Small letters indicate no significant differences between means according to Tukey test at p= 0.05

The daily decomposition rate of daily nitrogen contributed by the three legume species evaluated (Table 7) varied from 0.114 and 0.135, with variations of one day (5 to 6 days) in the average time of decomposition.

The nitrogen contributed by the legume species that were evaluated had a faster decomposition rate than the decomposition of residues; this agrees with the study conducted by Resende (2000), where residues of legumes evaluated deteriorated in a period of time of 45 days and the mineralisation of nitrogen varied from 14 to 35 days; unlike this study, the residues were left on the floor.

This apparently is because most of the nitrogen is found in the tissues and decompose more rapidly, fixing a small part of the nitrogen compared to more recalcitrant compounds such as lignin and polyphenols, which have slower decomposition (Resende, 2000).

The daily decomposition of nitrogen at various times varied from 0.107 to 0.131, and similar mineralisation was observed between Time 1 and Time 3. The rate of mineralisation was also similar. The highest rate was during Time 3 (first week of July sowing) where nitrogen is mineralised in a period of 5 days.

\[T_{1/2} = \text{Time in which 50% of residues are away from the bag}\]
Table 8—Average effect of the sowing date on rate and nitrogen mineralisation time.

<table>
<thead>
<tr>
<th>Sowing time</th>
<th>Decomposition rate (k)</th>
<th>Average time of decomposition (T_{1/2} days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time 1 (Starting on 06–06–06)</td>
<td>0.130</td>
<td>6</td>
</tr>
<tr>
<td>Time 2 (Starting on 21–06–06)</td>
<td>0.107</td>
<td>7</td>
</tr>
<tr>
<td>Time 3 (Starting on 06–07–06)</td>
<td>0.131</td>
<td>5</td>
</tr>
<tr>
<td>CV = 16.18</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Conclusions

The rotation of the three species of legumes produced on average more sugarcane seed cane compared to the commercial control without rotation and properly fertilised. Increases were observed of 7.3 and 4.6 t/ha, respectively, with the rotation of *Canavalia Ensiformis* and *Mucuna* sp.

It was determined that *Crotalaria juncea* accumulated an average of 349 kg N/ha to 50 t/ha of biomass in 60 days while *Mucuna* sp and *Canavalia ensiformis* accumulated on average 216 and 144 kg N/ha in the same period.

Half time degradation of the aerial biomass of the legume species took 17 to 20 days with similar daily rates of decomposition; the average time of nitrogen decomposition was 5 to 6 days with similar rates between sowing times.

The average time for degradation of nitrogen between sowing times varied from 5 to 7 days, in Time 2, which was planted on June 21st 2006, and had a lower daily rate of decomposition (k=0.107) than the other two studied.

Acknowledgments

The principal author wishes to thank Mr Fraterno Vila, Director of the Board of Directors of San Diego-Trinidad Corporation for his valuable support to this research. Also CENGICAÑA’S staff who helped with laboratory analysis and important suggestions to this study.

REFERENCES


CROTALARIA JUNCEA, CANAVALIA ENSIFORMIS ET MUCUNA SP COMME SOURCES POSSIBLES D'AZOTE DANS LES PEPINIERES COMMERCIALES DE CANNE À SUCRE

Par

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MOTS-CLÉS: Minéralisation d'Azote, Engrais Vert, Rotation.

Résumé

Les objectifs de cette étude étaient : a) d'évaluer la rotation de \textit{Crotalaria juncea}, \textit{Canavalia ensiformis} et \textit{Mucuna sp} et leur effet sur la production de canne à sucre après trois semis. b) de déterminer la décomposition de ces légumineuses, et de mesurer leur contribution en azote au système. Une expérimentation a été menée sur un Mollisol de la Finca El Naranjo, situé dans les zones basses de la région sucrière du Guatemala. Trois espèces des légumineuses ont été évaluées pour trois dates hivernales de semis, en commençant les semis le 6 juin 2006 et en les répétant tous les 15 jours pour les dates suivantes. Dans tous les traitements, la plantation de canne à sucre a été réalisée deux mois après le semis des légumineuses. Deux traitements supplémentaires ont été inclus, la pratique commerciale sans légumineuses et un témoin sans légumineuses et sans N. Les parcelles de canne avec légumineuses n'ont pas été fertilisées avec de l'azote. Le dispositif expérimental était constitué de blocs complets randomisés avec trois répétitions. Les parcelles principales comportaient les dates de semis et les parcelles secondaires, les trois espèces des légumineuses. La méthodologie utilisée pour mesurer la décomposition des légumineuses fut celle employée par Resende \textit{et al.} (1999). Des sacs contenant des légumineuses furent enterrés dans les parcelles correspondantes puis évalués 7, 14, 21, 35, 60, 75 et 120 jours après la récolte et l'incorporation des légumineuses. Pour estimer le taux de décomposition nous avons utilisé le modèle de Thomas et Asakawa, cité par Resende (2000). Tous les traitements où les légumineuses ont été incorporées ont entraîné une production de canne supérieure à celle de la pratique commerciale. Ainsi \textit{Canavalia ensiformis} produisit 7.4 TCH de plus que le témoin commercial fertilisé. Pendant la période d'évaluation, l'accumulation d'azote provenant des légumineuses fut comprise entre 144 et 349 kg de N/ha, \textit{Crotalaria juncea} étant la légumineuse ayant la production d'azote la plus élevée. La demi période de décomposition des légumineuses fut comprise entre 17 à 20 jours, alors que la demi période de minéralisation de l'azote variait de 5 à 7 jours. La demi période de décomposition la plus basse fut observée chez \textit{Mucuna sp}, et la demi période de minéralisation de l'azote fut observée chez \textit{Crotalaria juncea}. 
CROTALARIA JUNCEA, CANAVALIA ENSIFORMIS Y MUCUNA SP COMO POSIBLES FUENTES DE NITRÓGENO EN LA FERTILIZACIÓN DE LA CAÑA DE AZÚCAR DE SEMILLEROS COMERCIALES

Por

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PALABRAS CLAVE: Mineralización del Nitrógeno, Abono verde, Rotación.

Resumen

Los objetivos de este estudio fueron: a) Evaluar la rotación con Crotalaria juncea, Canavalia ensiformis y Mucuna sp y su efecto en la producción de caña de azúcar durante tres fechas de siembra. b) Determinar la descomposición de las plantas leguminosas, y cuantificar la contribución de nitrógeno de cada una al sistema. Se realizó un experimento en un suelo Mollisol de la Finca El Naranjo, ubicado en la zona baja de la región azucarera de Guatemala, evaluándose las tres especies de leguminosas, en tres fechas de siembra invernales, comenzando con el cultivo de las leguminosas el 6 de junio de 2006, y repitiéndose cada 15 días para fechas posteriores. En todos los casos, la plantación de caña de azúcar se hizo dos meses después de la siembra de las leguminosas. Se incluyeron dos tratamientos más: la práctica comercial sin leguminosas y un testigo sin leguminosas y sin N. Las parcelas de caña con leguminosas no fueron fertilizados con nitrógeno. El diseño experimental utilizado fue de bloques completos al azar con tres repeticiones. La época de siembra constituyó las parcelas principales y las sub-parccllas fueron las tres especies de leguminosas. Con el fin de cuantificar la descomposición de las leguminosas, la metodología utilizada fue la misma que la propuesta por Resende et al. (1999) en la cual se utilizan bolsas de la degradación enterradas bajo las parcelas que se evaluaron a los 7, 14, 21, 35, 60, 75 y 120 días posteriores a la incorporación de las leguminosas. Para estimar la tasa de descomposición se utilizó el modelo de Thomas y Asakawa, citado por Resende (2000). Los resultados indicaron que todos los tratamientos donde las leguminosas se incorporaron superaron al control comercial en términos de producción de semillas de la caña de azúcar. Canavalia ensiformis produjo 7,4 TCH más que los que fueron fertilizados. La acumulación de nitrógeno de las leguminosas fue de entre 144 y 349 kg de N/ha durante el periodo de evaluación donde Crotalaria juncea fue la de mayor contribución. El tiempo promedio de la mitad de descomposición de las leguminosas fue similar y varió desde 17 hasta 20 días, mientras que el tiempo medio de mineralización de nitrógeno fue de 5 a 7 días, con Mucuna sp presentando el menor promedio de tiempo de media descomposición de los residuos. El tiempo más bajo de la mitad de mineralización del nitrógeno registrado fue el de la Crotalaria juncea.
PRELIMINARY RESULTS OF A NETWORK OF TRIALS RELATED TO SUGARCANE NUTRITION IN REUNION ISLAND

By

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KEYWORDS: Saccharum spp., Sugarcane, Agronomical Trials, Fertilisation.

Abstract

IN REUNION ISLAND, sugarcane is grown under highly contrasting climatic conditions, from the sea level to the highlands (up to 1000 m altitude), with very different soil types. Taking this diversity into account, a network of agronomic trials was implemented in 2005 on grower farms across the island. Four main fertilisation or amelioration techniques were tested: i) reduction of soil acidity using mill ash compared to liming materials, Mag lime and Physiolith; ii) sustainable nutrient management based on soil analysis, iii) effect of a slow release fertiliser-polymer-coated granular urea and iv) effect of splitting nitrogen application. In each trial, the traditional grower practices were used as control. Outcomes of the trials included: correction of soil acidity using mill ash with a sugar yield 10 to 23% higher than the control; a better sugar yield per ha using sustainable nutrient management (in one of two trials); a sugar yield loss using a reduced rate (–30%) of polymer-coated granular urea; a positive impact on ratoon yield when nitrogen application was split into two events. Such a network of trials should facilitate a faster adoption of research recommendations by the growers as it allows a direct exchange of information between sugarcane farmers and agronomists and addresses growers’ issues.

Introduction

Reunion Island is a volcanic island in the Indian Ocean, located at 55°30’ longitude east, and 21°05’ latitude south, with an area of 2510 km² and the highest summit of 3069 m whose soil types are results of:

- The age of lava flows issued from the two volcanos that created the island.
- Varying climatic conditions characterised by a huge rainfall gradient from 600 to more than 4000 mm in sugarcane areas.

The soils are silty clay textured; well-drained and varied in fertility. Heavy applications of phosphorus may be necessary in andic cambisol soil types, whereas their potassium level is naturally very high (Fillols et al., 2007).

In nitisol and andic cambisol soil types, a moderate nitrogen application is generally required. Considering all soil types within the sugarcane area, 36% have pH<5 and 26% have pH between 5 and 5.5, so liming is often advised.
Sugarcane is grown on about 26,000 ha from sea level up to 1000 m altitude and there are slightly fewer than 4000 sugarcane growers. Their farm management practices often differ from the recommendations given by research and development institutes, especially in terms of nutrient management.

A network of trials has been implemented since 2005 on growers’ farms across the island in order to facilitate the adoption of technical advice by farmers. These trials also take into account the island diversity and help researchers to refine their recommendations.

Materials and methods

In total, nine trials have been implemented: eight on grower’s farms across the island and one (T4) in an experimental station (Table 1)

<table>
<thead>
<tr>
<th>Trial</th>
<th>Site</th>
<th>Altitude (m)</th>
<th>Rainfall (mm)</th>
<th>Soil type</th>
<th>pH (water)</th>
<th>Number of harvests</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>Bourbier les Hauts</td>
<td>150</td>
<td>3300</td>
<td>Andosol</td>
<td>4.6</td>
<td>3</td>
</tr>
<tr>
<td>T2</td>
<td>Sainte Marie Hauts</td>
<td>400</td>
<td>2800</td>
<td>Andic Nitisol</td>
<td>4.7</td>
<td>3</td>
</tr>
<tr>
<td>T3</td>
<td>La Rivière</td>
<td>460</td>
<td>1250</td>
<td>Andosol</td>
<td>4.3</td>
<td>2</td>
</tr>
<tr>
<td>T4 (I)</td>
<td>La Mare Ste Marie</td>
<td>50</td>
<td>1900</td>
<td>Nitisol</td>
<td>5.2</td>
<td>3</td>
</tr>
<tr>
<td>T5</td>
<td>Piton Sainte Rose</td>
<td>340</td>
<td>3600</td>
<td>Nitisol</td>
<td>6.0</td>
<td>3</td>
</tr>
<tr>
<td>T6</td>
<td>Sainte Anne</td>
<td>80</td>
<td>3500</td>
<td>Andic Cambisol</td>
<td>4.9</td>
<td>3</td>
</tr>
<tr>
<td>T7</td>
<td>Sainte Marie Bas</td>
<td>100</td>
<td>1900</td>
<td>Nitisol</td>
<td>5.6</td>
<td>2</td>
</tr>
<tr>
<td>T8</td>
<td>Saint Joseph</td>
<td>400</td>
<td>2000</td>
<td>Andosol</td>
<td>5.6</td>
<td>3</td>
</tr>
<tr>
<td>T9</td>
<td>Vincendo</td>
<td>20</td>
<td>2200</td>
<td>Andic Cambisol</td>
<td>5.2</td>
<td>2</td>
</tr>
</tbody>
</table>

(I): Irrigated

Four topics studied are:
- Liming products: mill ash, Mag lime, Physiolith® (calcified seaweed) (Tables 2 and 3).
- Split nitrogen applications: one application of nitrogen full rate in the furrow at planting (Table 4, T4-M1 and T5-M1), 1/2 rate N at planting then 1/2 rate 2 months later (Table 4, T4-M2 and T5-M2), 1/3 rate N at planting, 1/3 rate 2 months later and 1/3 rate at 4 months (Table 4, T5-M3). In ratoons, the first application of nitrogen was done at 2 months after harvesting and the following applications were done at 2 months apart.
- Physical forms of urea fertiliser: prill urea, coated urea.
- Sustainable nutrient management using soil analysis compared to traditional growers’ practice (Table 5).

<table>
<thead>
<tr>
<th>Liming product</th>
<th>CaO%</th>
<th>MgO%</th>
<th>P₂O₅%</th>
<th>K₂O%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mill ash</td>
<td>5</td>
<td>2.6</td>
<td>1.7</td>
<td>2.1</td>
</tr>
<tr>
<td>Mag lime</td>
<td>59</td>
<td>39</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Physiolith® granulated</td>
<td>36</td>
<td>2.5</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>
Table 3—Trials on liming products. Nutrients applied in kg/ha/y (plant cane/ratoon).

<table>
<thead>
<tr>
<th>Trial</th>
<th>Liming product</th>
<th>From fertiliser</th>
<th>From fertiliser/mill ash</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type</td>
<td>t/ha</td>
<td>CaO</td>
</tr>
<tr>
<td>T1</td>
<td>Mill ash</td>
<td>62 (1)</td>
<td>3120/0</td>
</tr>
<tr>
<td></td>
<td>Mag lime</td>
<td>2</td>
<td>1180/0</td>
</tr>
<tr>
<td></td>
<td>Physiolith®</td>
<td>1.2</td>
<td>490/0</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>0</td>
<td>0/0</td>
</tr>
<tr>
<td>T2</td>
<td>Mill ash</td>
<td>55 (1)</td>
<td>2770/0</td>
</tr>
<tr>
<td></td>
<td>Mag lime</td>
<td>2</td>
<td>1180/0</td>
</tr>
<tr>
<td></td>
<td>Physiolith®</td>
<td>1.2</td>
<td>490/0</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>0</td>
<td>0/0</td>
</tr>
<tr>
<td>T3</td>
<td>Mill ash</td>
<td>95 (1)</td>
<td>4200/0</td>
</tr>
<tr>
<td></td>
<td>Mag lime</td>
<td>2</td>
<td>1180/0</td>
</tr>
<tr>
<td></td>
<td>Physiolith®</td>
<td>1.2</td>
<td>490/0</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>0</td>
<td>0/0</td>
</tr>
</tbody>
</table>

(1): dry weight

Soils in all trial sites were sampled and analysed before planting. Liming products and nutrients were applied according to the recommendations of the soil laboratory, unless specified otherwise in the trial procedures (Pouzet et al., 1997).

Liming products were buried prior to planting. If not specified otherwise in the procedures, fertilisers were localised in the furrow at planting and between one and two months after harvest in ratoons. Soil testing was done at least once a year after harvest.

The same trial design was used in all trials, with three replicates and plot size of 20 m * 9 rows, comprising four guard rows, two rows for measurements of stalk number, growth foliar analysis and CCS, and three central rows for yield assessment.

An economic study consisted here of comparing the gross margin in €/ha/y obtained in a tested treatment to the one that resulted from the grower’s usual practice (control).

The expenses taken into account were the cost of products per hectare (liming products, fertilisers), transportation, mechanical application and incorporation (liming products), and application by hand (fertilisers).

All other farming practices were considered similar between treatments and not taken into account in the calculation. Costs of cane hauling and transport after harvest were not included.

The income calculation was based on the payment of cane for a CCS of 13.8%. It was calculated for a 10 ha average farm and the different governmental subsidies were added.

Table 4—Trials on split nitrogen application and different physical forms of urea nutrients applied in kg/ha/y (plant cane/ratoon).

<table>
<thead>
<tr>
<th>Trial</th>
<th>Treatment</th>
<th>N</th>
<th>P₂O₅</th>
<th>K₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>T4</td>
<td>M1 Prill urea * 1 application</td>
<td>170/170</td>
<td>128/120</td>
<td>300/280</td>
</tr>
<tr>
<td></td>
<td>M2 Prill urea * 2 applications</td>
<td>160/160</td>
<td>690/260</td>
<td>490/490</td>
</tr>
<tr>
<td></td>
<td>M3 Coated urea * 1 application</td>
<td>165/165</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>M4 Coated urea – 30% * 1 application</td>
<td>120/120</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>M5 NPK granular fertiliser</td>
<td>176/176</td>
<td>110/110</td>
<td>286/286</td>
</tr>
<tr>
<td>T5</td>
<td>M1 Prill urea * 1 application</td>
<td>160/160</td>
<td>690/260</td>
<td>490/490</td>
</tr>
<tr>
<td></td>
<td>M2 Prill urea * 2 applications</td>
<td>160/160</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>M3 Prill urea * 3 applications</td>
<td>165/165</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T6</td>
<td>NR Coated urea * 1 application</td>
<td>130/130</td>
<td>90/90</td>
<td>260/260</td>
</tr>
<tr>
<td></td>
<td>NT Prill urea * 1 application</td>
<td>155/155</td>
<td>90/90</td>
<td>260/260</td>
</tr>
<tr>
<td>T7</td>
<td>NR Coated urea * 1 application</td>
<td>155/155</td>
<td>90/90</td>
<td>260/260</td>
</tr>
<tr>
<td></td>
<td>NT Prill urea * 1 application</td>
<td>155/155</td>
<td>90/90</td>
<td>260/260</td>
</tr>
</tbody>
</table>
Table 5—Trials on sustainable nutrient management Nutrients applied in kg/ha/y (plant cane/ratoon).

<table>
<thead>
<tr>
<th>Trial</th>
<th>Treatment</th>
<th>N</th>
<th>P&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;5&lt;/sub&gt;</th>
<th>K&lt;sub&gt;2&lt;/sub&gt;O</th>
<th>CaO</th>
<th>MgO</th>
</tr>
</thead>
<tbody>
<tr>
<td>T8</td>
<td>FC SNM</td>
<td>140/143</td>
<td>560/217</td>
<td>210/217</td>
<td>590/0</td>
<td>390/0</td>
</tr>
<tr>
<td></td>
<td>FT GNM</td>
<td>195/144</td>
<td>156/56</td>
<td>312/216</td>
<td>0/0</td>
<td>0/0</td>
</tr>
<tr>
<td>T9</td>
<td>FC SNM</td>
<td>120/160</td>
<td>0/0</td>
<td>0/264</td>
<td>1180/0</td>
<td>780/0</td>
</tr>
<tr>
<td></td>
<td>FT GNM</td>
<td>150/156</td>
<td>120/80</td>
<td>240/240</td>
<td>410/0</td>
<td>270/0</td>
</tr>
</tbody>
</table>

SNM: Sustainable nutrient management. GNM: Grower’s nutrient management.

Results and discussion

Trials on liming products

These trials were implemented on farms where the soil was very acidic and the soil analysis recommended 3.5 to 4 t/ha of CaO + 1.8 to 2 t/ha MgO. However, liming products in Reunion are expensive and growers cannot afford to apply these high rates. This is the reason why Mag lime and Physiolith®, 2 commercial liming products, have been applied at reduced rate in the trials, whereas the full advised rate of mill ash has been used.

In all trials, the application of mill ash, Mag lime and Physiolith® significantly increased cane yield by 19.0%, 15.2% and 14.0% respectively, and sugar yield by 24.0%, 18.1% and 15.5% respectively, compared to the control (Table 6). However, there was no statistical difference in yield response between the three products.

The values of foliar and soil analysis should reflect the nutritional status of the plant and the fertility status of the soil according to the treatments applied, but are not always significantly correlated with cane and sugar yield. Mill ash treatment tended to improve soil parameters (Barry et al., 2001), especially calcium, magnesium, pH and CEC. In trial T3, the mill ash treatment significantly improved soil pH, Ca (Figure 1) and Mg values, but did not affect levels of nutrients in the leaves. In trial T1, foliar values of Ca and Mg were significantly higher in the mill ash treatment than in the Physiolith® and in the control treatments (data not included in this report).

Table 6—Trials on liming products – Cane yield, sugar yield and difference of gross margin compared to the control in €/ha/y 3-year yield average (T1 + T2) – 2-year yield average (T1 + T2 + T3).

<table>
<thead>
<tr>
<th>Treatments</th>
<th>T1 + T2 (3 years)</th>
<th>T1 + T2 + T3 (2 years)</th>
<th>Gross margin €/ha/y</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>tc/ha/y</td>
<td>ts/ha/y</td>
<td>tc/ha/y</td>
</tr>
<tr>
<td>Mill ash</td>
<td>102.8 a</td>
<td>14.4 a</td>
<td>108.5 a</td>
</tr>
<tr>
<td>Mag lime</td>
<td>98.5 a</td>
<td>13.4 a</td>
<td>107.9 a</td>
</tr>
<tr>
<td>Physiolith®</td>
<td>99.5 a</td>
<td>13.7 a</td>
<td>106.7 a</td>
</tr>
<tr>
<td>Control</td>
<td>86.4 b</td>
<td>11.6 b</td>
<td>95.1 b</td>
</tr>
<tr>
<td>Mean</td>
<td>96.8</td>
<td>13.3</td>
<td>104.5</td>
</tr>
<tr>
<td>CV%</td>
<td>12.3</td>
<td>14.3</td>
<td>11.8</td>
</tr>
<tr>
<td>P</td>
<td>0.001</td>
<td>0.000</td>
<td>0.005</td>
</tr>
</tbody>
</table>

Means in columns followed by the same letter are not significantly different (P = 0.05)

Physiolith® at 1.2 t/ha significantly improved cane and sugar yield compared with the control but did not significantly affect the soil parameters (pH, nutrients). This input represents a small amount of calcium (5.7 to 8.6 times less than mill ash and 2.4 times less than Mag lime) which is insufficient to influence soil cations and pH.

Trials on split nitrogen application and different physical forms of urea fertiliser

For split nitrogen application, there was no significant difference in cane yield, sugar yield or gross margin between a single, two and three applications, which was consistent with the results obtained by K.F. Ng Kee Kong and Deville (1992). However, splitting nitrogen in two applications...
trials T4 and T5, M2) tended to increase cane yield compared to a single application: +5.8% in T4 and +5.1% in T5. Gross margin was increased by 290 €/ha/y in the irrigated trial T4 and by 180 €/ha/y in the non-irrigated trial T5 compared to a single application.

Application of a common granulated NPK fertiliser 16-10-26 just after harvest (T4 – M5) was economically cheaper (+227 €/ha/y) than applying single nutrients: urea + TSP + KCl. Splitting urea in three applications resulted in a cane loss of –7.4 t/ha/y and reduced the benefit by –360 €/ha/y (not significant).

In trials T6 and T7 (Table 7), coated urea (NR) improved cane yield by 7.5% and 4.4% respectively and gross margin by +465 and +180 €/ha/y respectively when compared to prill urea (result was not significant).

Table 7—Trials on split nitrogen application and different physical forms of urea fertiliser. Average of cane yield (tc/ha/y) and sugar yield (ts/ha/y) and difference of gross margin compared to the control in €/ha/y.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Treatments</th>
<th>tc/ha/y</th>
<th>ts/ha/y</th>
<th>Gross margin €/ha/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>T4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average of 3 years</td>
<td>M1 Prill urea * 1 application</td>
<td>101.6</td>
<td>14.3</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>M2 Prill urea * 2 applications</td>
<td>107.5</td>
<td>15.1</td>
<td>+ 290</td>
</tr>
<tr>
<td></td>
<td>M3 Coated urea * 1 application</td>
<td>94.2</td>
<td>13.1</td>
<td>– 720</td>
</tr>
<tr>
<td></td>
<td>M4 Coated urea – 30% * 1 appl.</td>
<td>97.8</td>
<td>13.6</td>
<td>– 349</td>
</tr>
<tr>
<td></td>
<td>M5 NPK granular fertiliser</td>
<td>105.8</td>
<td>14.6</td>
<td>+ 227</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>101.4</td>
<td>14.1</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>CV%</td>
<td>10.0</td>
<td>11.7</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>P</td>
<td>0.54</td>
<td>0.11</td>
<td>–</td>
</tr>
<tr>
<td>T5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average of 3 years</td>
<td>M1 Prill urea * 1 application</td>
<td>88.2</td>
<td>11.9</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>M2 Prill urea * 2 applications</td>
<td>92.7</td>
<td>12.2</td>
<td>+ 180</td>
</tr>
<tr>
<td></td>
<td>M3 Prill urea * 3 applications</td>
<td>87.2</td>
<td>11.4</td>
<td>– 380</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>89.4</td>
<td>11.8</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>CV%</td>
<td>11.1</td>
<td>10.8</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>P</td>
<td>0.48</td>
<td>0.41</td>
<td>–</td>
</tr>
<tr>
<td>T6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average of 3 years</td>
<td>NR Coated urea * 1 application</td>
<td>112.0</td>
<td>17.4</td>
<td>+ 465</td>
</tr>
<tr>
<td></td>
<td>NT Prill urea * 1 application</td>
<td>104.2</td>
<td>16.1</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>108.1</td>
<td>16.7</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>CV%</td>
<td>12.1</td>
<td>13.0</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>P</td>
<td>0.23</td>
<td>0.22</td>
<td>–</td>
</tr>
<tr>
<td>T7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average of 2 years</td>
<td>NR Coated urea * 1 application</td>
<td>105.1</td>
<td>14.2</td>
<td>+ 180</td>
</tr>
<tr>
<td></td>
<td>NT Prill urea * 1 application</td>
<td>100.7</td>
<td>13.9</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>102.9</td>
<td>14.1</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>CV%</td>
<td>17.2</td>
<td>17.5</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>P</td>
<td>0.68</td>
<td>0.87</td>
<td>–</td>
</tr>
</tbody>
</table>
In trial T4, the quality of the coated urea used in M3 plant cane was dubious and may lead to poor results obtained in M3 plant cane. The faulty cane establishment also seemed to affect development of the ratoons resulting in mediocre cane yield for 3 years.

In the coated urea product, urea was protected by a resin coat which slows down urea solubility. This slow release nitrogen fertiliser should improve plant uptake and reduce losses to the environment compared with normal prill urea. A reduced application rate was tested in order to compensate for the high cost of the product (60% more expensive than prill urea in Reunion Island in 2008). However, reducing the rate of coated urea by 30% (T4 – M4) induced cane yield loss of –3.8 t/ha/y and decreased the benefit by 349 €/ha/y compared to applying the full rate of prill urea.

**Trials on sustainable nutrient management**

The two trials on the use of a sustainable nutrient management program led to opposite outcomes.

In trial T8 (Table 8), cane yield increased by 13% where the sustainable nutrient management treatment (FC) was applied compared to the traditional grower’s nutrient management practice (FT) and the gross margin was 646 €/ha/y higher (not significantly different). Mag lime incorporated in the soil prior to planting in treatment FC progressively modified soil pH and composition in exchangeable Ca and Mg (Figure 2).

| Table 8—Trials on sustainable nutrient management. Average of cane yield (tc/ha/y) and sugar yield (ts/ha/y) and difference of gross margin compared to the control in €/ha/y. |
|---|---|---|---|---|
| **Trial** | **Treatments** | **tc /ha/y** | **ts/ha/y** | **Gross margin €/ha/y** |
| **T8** | Sustainable nutrient management | 99.7 | 13.1 | + 646 |
| Average of 3 years | Grower’s nutrient management (control) | 87.6 | 11.6 | – |
| Mean | 93.6 | 12.4 | – |
| CV% | 19.1 | 19.0 | – |
| P | 0.18 | 0.21 | – |
| **T9** | Sustainable nutrient management | 122.8 | 15.4 | – 1461 |
| Average of 2 years | Grower’s nutrient management (control) | 146.4 | 18.1 | – |
| Mean | 134.6 | 16.7 | – |
| CV% | 17.0 | 15.3 | – |
| P | 0.111 | 0.113 | – |

In trial T9, there was no significant difference between the two treatments. However, cane yield obtained by the grower nutrient management practice (FT) was 16% higher than in the sustainable nutrient management treatment (Table 8).

**Fig. 2—Trial T8:** – Impact of Mag lime on soil pH (A) and on soil exchangeable Ca and Mg (B). a, b: significant difference if different letters.
This may result from an abnormally high yield in one FT subplot (+35% higher than the yield average for the trial). In the past, pig manure was frequently spread but unevenly across the field. The soil was very rich in nutrients when the trial started and the fertilisation recommendations were advised accordingly.

A significant difference between the two treatments appeared in the second ratoon for soil pH ($P=0.035$), exchangeable Ca ($P=0.015$) and Mg ($P=0.005$). These significant differences vanished in the third ratoon, possibly meaning that the rate of liming products applied was not sufficient for a lasting efficacy.

The recommendations were also calculated on the basis of a high yield potential for the region. The yield obtained on this field in the grower treatment (FT) exceeded the maximum yield potential originally assessed. This may imply that the recommendations for the sustainable nutrient management treatment were under-estimated. This result highlighted the need to refine the calculation system for fertiliser recommendations based on soil analysis and potential yield.

**Conclusion**

Implementation and follow-up of this network of trials across Reunion Island was challenging but the data obtained will help to adjust or confirm technical advice on nutrient management currently given to sugarcane growers.

Eight trials out of nine were carried out on growers’ farms. The same trends are observed in similar trials, but statistically significant differences between treatments occurred in only four trials. It is likely that the small number of replicates and the few treatments tested explain this lack of precision.

In order to obtain results with significant differences, additional treatments and/or replicates could be considered for future trials. Plot size could be reduced to five rows * 15 m instead of nine rows * 20 m to keep the total size of each trial manageable.

One main outcome of the work is the positive impact of the liming products tested (mill ash, Mag lime and Physiolith®) compared to the un-limed control, with an increase in gross margin of 1575 €/ha/y, 678 €/ha/y and 591 €/ha/y respectively if cane hauling and transport are not taken into account. Mill ash application systematically increases soil pH (significant difference in one trial).

Compared to one single application, splitting nitrogen in two applications resulted in an increase of gross margin by 290 and 180 €/ha/y in the two test trials. Splitting nitrogen into three applications penalised cane production. When compared to a single application of a granulated NPK fertiliser, splitting nitrogen in two did not improve cane yield.

In two trials out of three, using coated urea instead of prill urea increased the gross margin by 180 €/ha and 465 €/ha. In the third trial, quality of the product delivered was dubious and no conclusion could be drawn.

Cane yield was not maintained when the coated formulation, designed for a slow nitrogen release, was applied at reduced rates (~30%).

In one trial, using the sustainable nutrient management strategy resulted in a benefit of 646 €/ha/y compared to the traditional grower fertilisation plan. In another trial, the grower’s practice performed better because the cane positively responded to the additional nutrients applied.

The sustainable nutrient management treatment, based on soil analysis and potential yield, underestimated the real yield potential and therefore advised an inadequately low amount of fertilisers. This last result highlights the need to refine the calculation system for fertiliser recommendations based on soil analysis and potential yield.

**REFERENCES**

RESULTATS PRELIMINAIRES D’UN RESEAU D’ESSAIS SUR LA NUTRITION DE LA CANNE A SUCRE A LA REUNION

Par

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MOTS CLES: Saccharum spp., Canne à Sucre, Essais Agronomiques, Fertilisation.

Résumé

A LA REUNION, la canne à sucre est cultivée dans des conditions climatiques très contrastées, du niveau de la mer jusqu’à 1000 m d’altitude, sur des types de sol très variables. En prenant en compte cette diversité, un réseau d’essais agronomiques a été implanté en 2005 chez des planteurs de canne à sucre de l’île. Quatre pratiques de fertilisation ont été testées: i) la réduction de l’acidité du sol en comparant l’utilisation de cendres de bagasse à des amendements chaulant – chaux magnésienne et Physiolith; ii) fertilisation raisonnée basée sur les données d’analyse de sol; iii) effet d’un engrais azoté retard comparé à de l’urée perlée et iv) l’effet d’un apport fractionné d’azote. Pour chaque essai, la pratique du planteur a servi de témoin. Les résultats de ces essais mettent en évidence: une correction de l’acidité du sol par les cendres de bagasse qui augmentent la production de sucre de 10 à 23% par rapport au témoin; un meilleur rendement sucre hectare quand la fertilisation est raisonnée (un essai sur deux); une perte de rendement sucre si la dose d’urée enrobée est réduite de 30%; un impact positif sur le rendement des repousses d’un fractionnement en 2 apports de l’urée. Un tel réseau d’essais devrait faciliter l’adoption des recommandations de la recherche par les planteurs car il permet un échange direct des informations entre ces derniers et les chercheurs.
RESULTADOS PRELIMINARES DE UNA SERIE DE ENSAYOS RELACIONADOS CON NUTRICIÓN DE CAÑA DE AZÚCAR EN LA ISLA REUNIÓN

Por

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PALABRAS CLAVE: Saccharum spp., Caña de Azúcar, Ensayos Agronómicos, Fertilización.

Resumen

EN LA ISLA REUNIÓN, la caña de azúcar se cultiva bajo condiciones climáticas altamente contrastantes, desde el nivel del mar hasta el altiplano (hasta 1000 m de altitud), en tipos de suelo muy diferentes. Tomando en cuenta esta diversidad, en 2005 se implementó una serie de ensayos agronómicos en fincas de productores, a lo largo de toda la isla. Se evaluaron cuatro técnicas principales de fertilización o enmienda: i) reducción de la acidez del suelo utilizando cenizas del ingenio, comparadas con cal – cal magnesiana y Physiolit; ii) manejo sostenible de nutrientes, basado en análisis de suelo; iii) efecto de urea granulada con una cubierta de un polímero de liberación lenta y iv) efecto de aplicaciones fraccionadas de nitrógeno. En cada experimento, se usó como testigo la práctica tradicional de los productores. Los resultados obtenidos incluyen: corrección de la acidez del suelo por el uso de cenizas del ingenio, con un rendimiento de 10 a 23% más que el testigo; un mejor rendimiento de azúcar por hectárea con el manejo sostenible de nutrientes (en uno de los dos ensayos); una pérdida en el rendimiento de azúcar por la reducción en la dosis de urea granular con una cubierta de un polímero de liberación lenta (~30%); un impacto positivo en el rendimiento en soca cuando el nitrógeno se suministró en dos aplicaciones. Esta serie de experimentos debería facilitar la adopción por parte de los productores, de las recomendaciones que surgen de las investigaciones, pues permite un intercambio directo de información entre agrónomos y productores, y están enfocados en las necesidades de estos últimos.
THE ROLE OF BIOCHAR IN MANAGEMENT OF SUGARCANE

By

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Abstract

THE SUGARCANE industry in many parts of the world produces food and energy (stationary and fuel). The industry is well positioned to offer greenhouse gas abatement and climate change mitigation. The thermal conversion, via a slow pyrolysis process, of cane residues such as green harvest trash and bagasse can produce additional thermal or electrical energy as well as biochar. Studies have shown that a commercial slow pyrolysis unit could generate over 2MWh of electricity from every four tonnes of dry trash, as well as 1.3 tonnes of biochar per hour. Biochar has characteristics similar to black carbon, and it has recently been suggested as a sequestration pathway to remove CO2 from the atmosphere, long term, due to its very stable chemical structure. One tonne of bagasse derived biochar would sequester in the order of 2.3 tonnes of CO2 equivalents. In addition to C sequestration, biochar has other significant benefits such as offering improved soil quality, CEC, moisture retention etc. It also has the potential to reduce emissions of greenhouse gases from cane soils, including nitrous oxide and methane. Biochars derived from cane trash and bagasse were applied in incubation studies to soils from the Burdekin region in Australia to test for reductions in emissions of greenhouse gases. We found significant declines in emissions of the greenhouse gas, nitrous oxide (N2O), from urea-fertilised soil when bagasse biochar was applied at a rate of 10 t/ha. The agronomic performance of biochar is being assessed in a 15 plot trial conducted on a sugarcane property in the Tweed Valley, NSW. Biochars from waste were tested and included paper mill biochar and council green waste biochar. Controls included lime treatments. Each plot used 3 rows of cane and was 30 m in length to enable commercial-scale harvesting. Although no significant effects in yield were recorded for year 1, this trial is expected to continue for two more seasons allowing additional data on yield effects to be demonstrated. Our work is demonstrating that implementation of slow pyrolysis and biochar utilisation in the sugarcane industry has potential to provide 1) renewable energy 2) income from waste 3) climate mitigation through stabilisation of carbon 4) climate mitigation through reduced emission of N2O from soil, and 5) improved soil fertility and agronomic performance.

Introduction

Anthropogenic enhancement of soil by the application of charcoal has been implemented for several thousand years. The Terra Preta, dark earth, soils of the Amazon (Glaser et al., 2001)
highlight the possibilities of biochar amendment, as these soils maintain very high fertility long after application, while surrounding soils remain poor.

Black carbon manufactured through pyrolysis of biomass has become known as ‘biochar’ (Lehmann et al., 2006). A wide range of biomass sources have been used to make biochar, including: woody materials, agricultural and food wastes (Demirbas, 2004; Ioannidou and Zabaniotou, 2007), greenwaste (Chan et al., 2007) animal manures (Chan et al., 2008) and wastes from the papermill industry (Van Zwieten et al., 2009a).

The application of biochar to soil can improve soil quality and plant growth (Chan et al., 2007; Chan et al., 2008) and reduce emissions of greenhouse gases (GHGs), in particular nitrous oxide (Yanai et al., 2007; Van Zwieten et al., 2009b). Furthermore, biochar is protected from rapid microbial degradation, enabling the carbon stored in biochar to remain for hundreds of years (Lehmann et al., 2006; Krull et al., 2009).

There are many technologies that are capable of making biochar products. These include slow and fast pyrolysis, carbonisation, charcoal retorts and gasification. Slow pyrolysis typically utilises a kiln that is heated externally to achieve temperatures of around 500°C with a residence time of the biomass at this temperature around 30 min (Brown, 2009).

Slow pyrolysis yields two key products, biochar and syngas, although some systems may also yield pyrolysis oil. The syngas is a combustible mixture of methane, hydrogen and carbon monoxide which can be used to generate the heat required to dry and pyrolyse the biomass, with surplus gas being available to generate renewable energy, such as electricity (Downie et al., 2007).

Recent work by Gaunt and Lehmann (2008) used a life cycle assessment approach to assess systems designed solely for energy production and compared these to pyrolysis which produced both energy and biochar. Their findings show that the avoided emissions of GHGs are between 2 and 5 times greater when biochar is applied to agricultural land (2–19 t CO₂/ha/yr) than when used solely for fossil energy offsets.

Between 41–64% of these emission reductions were credited to the retention of C in biochar, the rest to offsetting fossil fuel use for energy, fertiliser savings, and avoided soil emissions other than CO₂. Despite a reduction in energy output of approximately 30% where the slow pyrolysis technology was optimised to produce biochar for land application, the energy produced per unit energy input at between 2 and 7 MJ/MJ is greater than that of comparable technologies such as ethanol from corn.

Additionally, this study by Gaunt and Lehmann (2008) showed that C emissions per MWh of electricity produced range from 91–360 kg CO₂/MWh. Even before accounting for C offset due to the use of biochar, this figure is considerably lower than the lifecycle emissions associated with fossil fuel use for electricity generation (600–900 kg CO₂/MWh).

**Slow-pyrolysis and the sugar industry**

Globally, the requirements for food and energy are increasing. The sugarcane industry is well positioned, in that it can offer both food and energy production, in the form of fuels (first and second generation), and stationary energy from crop residues such as lignin wastes, bagasse and trash.

It provides these products without increasing the quantity of greenhouse gases in the atmosphere. Climate mitigation can be achieved through both displacing fossil fuels, as well as the conversion of labile organic carbon into very stable organic carbon (biochar) that is used as a soil amendment.

Recent work has demonstrated sugarcane residues can generate energy in the form of electricity through combustion of the syngas (methane, hydrogen and carbon monoxide) in a gas engine. Table 1 summarises results:
Table 1—Conversion of sugarcane waste into biochar and energy.

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>Biochar yield (dry basis) %</th>
<th>Syngas energy produced (MW/tonne dry feed)</th>
<th>Electricity production (MWh/tonne dry feed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugarcane trash</td>
<td>33.6</td>
<td>1.33</td>
<td>0.5</td>
</tr>
<tr>
<td>Bagasse</td>
<td>31.3</td>
<td>1.35</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Notes: Pyrolysed at a highest heating temperature of 550°C with mean residence time at this temperature of 40 minutes and a heating rate of 5°C/min. The electricity output is based on the use of a gas engine at 37% conversion efficiency. It should be noted that larger scale applications may use gas or steam cycle turbines with differing conversion efficiencies.

The ultimate analysis (Australian Standards 1038.6.3.3 method) revealed that the molar H/C ratio of feedstock was 1.50 and 1.45 for the trash and bagasse respectively, and this reduced to 0.45 for trash biochar and 0.43 for bagasse biochar. This indicates the disproportional loss of hydrogen as the carbon forms more stable, conjugated aromatic structures. In a review by Krull et al. (2009), it is suggested temperatures above 400°C form chars with H/C ratios below 0.5, and that these ratios demonstrate aromaticity and maturation. In recent work by Kuzyakov et al. (2009), biochars made at temperatures of 400°C were shown to have a turnover rate of around 2000 years. The sugarcane waste biochars in this study were produced at higher temperature (although lower residence time). Therefore, it can be expected that when applied in soil, they will remain there for many hundreds of years, highlighting their climate mitigation potential.

Table 2—Chemical analysis of feedstocks and biochars.

<table>
<thead>
<tr>
<th></th>
<th>Trash feedstock</th>
<th>Bagasse feedstock</th>
<th>Trash biochar</th>
<th>Bagasse biochar</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC</td>
<td>dS/m</td>
<td>na</td>
<td>4.8</td>
<td>0.18</td>
</tr>
<tr>
<td>pH (CaCl₂)</td>
<td>pH units</td>
<td>na</td>
<td>9.6</td>
<td>8.4</td>
</tr>
<tr>
<td>Bray 1 Phosphorus</td>
<td>mg/kg</td>
<td>na</td>
<td>250</td>
<td>67</td>
</tr>
<tr>
<td>KCl extractable Ammonium–N</td>
<td>mg/kg</td>
<td>20</td>
<td>0.73</td>
<td>2.2</td>
</tr>
<tr>
<td>KCl extractable Nitrate-N</td>
<td>mg/kg</td>
<td>7.5</td>
<td>&lt;0.20</td>
<td>&lt;0.20</td>
</tr>
<tr>
<td>Total Nitrogen</td>
<td>%</td>
<td>0.61</td>
<td>0.64</td>
<td>1.2</td>
</tr>
<tr>
<td>Total Potassium</td>
<td>%</td>
<td>0.64</td>
<td>0.14</td>
<td>2</td>
</tr>
<tr>
<td>Total Phosphorus</td>
<td>%</td>
<td>0.074</td>
<td>0.17</td>
<td>0.25</td>
</tr>
<tr>
<td>Total Carbon</td>
<td>%</td>
<td>41</td>
<td>38</td>
<td>68</td>
</tr>
</tbody>
</table>

Exchangeable Cations

<table>
<thead>
<tr>
<th></th>
<th>cmol(+)/kg</th>
<th>na</th>
<th>na</th>
<th>na</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>cmol(+)/kg</td>
<td>na</td>
<td>&lt;0.03</td>
<td>&lt;0.03</td>
</tr>
<tr>
<td>Calcium</td>
<td>cmol(+)/kg</td>
<td>na</td>
<td>6.4</td>
<td>2.1</td>
</tr>
<tr>
<td>Potassium</td>
<td>cmol(+)/kg</td>
<td>na</td>
<td>27</td>
<td>0.94</td>
</tr>
<tr>
<td>Magnesium</td>
<td>cmol(+)/kg</td>
<td>na</td>
<td>5.3</td>
<td>0.25</td>
</tr>
<tr>
<td>Sodium</td>
<td>cmol(+)/kg</td>
<td>na</td>
<td>0.9</td>
<td>0.25</td>
</tr>
<tr>
<td>CEC</td>
<td>cmol(+)/kg</td>
<td>na</td>
<td>40</td>
<td>3.5</td>
</tr>
<tr>
<td>Calcium/Magnesium</td>
<td>cmol(+)/kg</td>
<td>na</td>
<td>1.2</td>
<td>8.5</td>
</tr>
<tr>
<td>Acid neutralising capacity</td>
<td>% CaCO₃</td>
<td>na</td>
<td>4.6</td>
<td>1.1</td>
</tr>
<tr>
<td>Molar H/C ratio</td>
<td>1.50</td>
<td>1.45</td>
<td>0.45</td>
<td>0.43</td>
</tr>
</tbody>
</table>

Trash biochar had high levels of total K, while levels of this mineral were lower in the bagasse biochar. In combustion systems like traditional co-generation facilities, alkali compounds such as potassium foul heat transfer surfaces, participate in slag formation in grate-fired units and contribute to the formation of fluidised bed agglomerates (Turn et al., 1997).
The concentrations of potassium in bagasse feedstock are not significant; however, concentrations in the cane trash would certainly contribute to fouling. These fouling problems are overcome through the use of slow pyrolysis. In addition, potassium, an important sugarcane nutrient, is recycled with an almost 100% efficiency back into the biochar for soil application.

Both biochars have small amounts of plant available P (Bray P), but negligible plant available N. The trash biochar has a CEC of 40 cmol(+)/kg, much higher than the bagasse biochar from these analyses or other CECs reported in the literature (Van Zwieten et al., 2009; Chan et al., 2007, 2008). This highlights their potential to be applied in conjunction with fertilisers to enhance fertiliser use efficiency.

The trash biochar had an acid neutralising capacity of 4.6% compared to agricultural lime. Previous research on biochar from papermill residues has demonstrated that much of this acid neutralising capacity from biochar comes from Ca complexes on the surface, such as hydroxides, oxides and carbonates (Van Zwieten et al., 2009).

Many of the biochar trials undertaken have used values of 10 t/ha application rate. This equates roughly to 1% w/w assuming incorporation into the 0–10 cm soil profile. Applications of this rate would be equivalent to increasing soil carbon from a hypothetical value of 2.0% to close to 2.5% carbon, assuming a bulk density of 1.5 g/cm³.

The application would be equivalent to a 200 kg application of K, which would satisfy the K requirement of the crop, as well as a minor addition of P. The pH of soil would be expected to increase, equivalent to an addition of 460 kg agricultural lime. The effects on soil fertility including CEC, however, can not be fully predicted and field assessments are necessary.

It has been estimated that over 2.5 Mt of unutilised biomass exists in the Australian sugarcane industry every year (Bernard Milford, pers. comm.). This waste biomass could generate around 156 MW/h of electricity if processed via slow pyrolysis, and close to 855 000 t biochar production annually.

Putting numbers into perspective, this would equate to ca. 350 000 t avoided CO₂ emissions through offsetting fossil fuels, and around 2 Mt CO₂ equivalents locked up in soil. An average motor vehicle travelling about 20 000 km per year emits an equivalent of 5.2 t CO₂ (US EPA, 2000). This would equate to offsetting emissions from around 500 000 motor vehicles.

**Reduction of non-CO₂ GHG emissions from soil**

Climate change caused by increase in atmospheric concentrations of greenhouse gases (GHGs) is predicted to cause catastrophic impacts (IPCC, 2006). Human-influenced sources of nitrous oxide (N₂O) contributed 3 GT CO₂e (carbon dioxide equivalents), around 8% of global emissions, in 2004.

It was estimated that agriculture was responsible for 42% of this total (Denman et al., 2007). Sources for N₂O emissions from soils include application of N fertilisers, biological N fixation and excreta of grazing animals. A range of factors influence the emission of N₂O including N application rate, crop type, fertiliser type, soil organic C content, soil pH and texture (Dalal et al., 2003).

Soil is both a significant source and sink for the greenhouse gases nitrous oxide (N₂O) and methane (CH₄). Emissions from sugarcane soils in Australia have shown very significant production of nitrous oxide (21% of applied N converted to N₂O) (Denmead et al., 2008). A total of 45.9 kg N/ha was emitted from a northern NSW sugarcane farm in the season following application of 160 kg N fertiliser.

As the global warming potential of N₂O is 298 times greater than the equivalent mass of CO₂ in the atmosphere (Forster et al., 2007), this equated to emissions of 43 t CO₂e/ha. Hence, small reductions in emissions could potentially provide significant benefits for climate mitigation.
Recent work by Van Zwieten et al. (2009b) has demonstrated the potential for biochar to reduce emissions of N$_2$O from soil. Current work using soils from the Burdekin region in Queensland, Australia, and bagasse and trash biochars are demonstrating very significant potential for reducing emissions of this potent GHG from soil.

Experimental microcosms containing soils from the Burdekin cane region in Queensland, Australia were used to demonstrate the GHG reduction potential of biochar. Soils were amended with biochars derived from trash and bagasse, to a rate of 10 t/ha equivalent, and compared to control (unamended) soil. Nitrogen was applied at either 0 or 165 kg/ha to all treatments. The atmosphere in the microcosms was analysed at days 1, 2, 4, 7 and 14. The microcosms were flooded at day 21, and the atmosphere was sampled again at days 21, 22, 23, 24, 28, 35, 42 and 49. Results for nitrous oxide emissions from the bagasse and trash biochars are depicted in Figures 1 and 2 respectively.

![Figure 1](image1.png)

**Fig. 1**—The production of nitrous oxide from control and bagasse biochar amended soils incubated with and without nitrogen amendment.

![Figure 2](image2.png)

**Fig. 2**—The production of nitrous oxide from control and trash biochar amended soils incubated with and without nitrogen amendment.

The control soil with 165 kg N/ha lost 0.7% of total nitrogen as N$_2$O in the 28 days following flooding. All of the N loss as N$_2$O was following flooding. Bagasse biochar significantly reduced N$_2$O emissions (0.55% of total N). A 21% reduction in N$_2$O emission compared to both fertilised control and 38% compared to the trash biochar (0.88% N loss) amended soils. The
bagasse biochar amended, fertilised soil had higher nitrate: ammonium N ratio than either the fertilised control or trash biochar amended soils. This indicates an improvement in N mineralisation through nitrification. Further losses could have been reduced by suppression of denitrification enzymes (Van Zwieten et al., 2009).

**Field assessment of biochar in sugarcane**

A field trial testing biochar was set up on the Tweed Valley, northern NSW. Plots were 30 m long and contained three rows of cane. The outside rows of the cane were used as buffers, and the inside row was used for soil analyses, GHG emissions testing and yield data. At the ends of each row, an additional 2 m buffer was used between plots. Treatments were allocated to experimental units in a randomised complete block design using the three rows of five plots as the blocking factor. Treatments included; control (standard farming practice), papermill biochar at 5 t/ha, council greenwaste biochar at 5 t/ha, council greenwaste biochar at 10 t/ha and lime (1.5 t/ha). Note the chemical properties of these biochars are different to the properties of the sugarcane derived biochars shown in the previous section.

Yield from the first season (2008) following planting is shown in Table 3. Yield measurements were assessed using standard commercial harvesting equipment, and weights of bins were recorded at the completion of each 30 m harvest length. Although no significant differences were seen with yield or leaf nutrient analysis in the first harvest, these trials are expected to continue until 2011, with annual harvesting. It is well recognised that the benefits of biochar application on crop yield may not be expected immediately, but develop over time as soil CEC increases upon biochar oxidation (Chan and Xu, 2009).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Yield (kg)</th>
<th>Std dev.</th>
<th>N in leaf tissue (% dry matter)</th>
<th>Std dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Papermill biochar 5 t/ha</td>
<td>433</td>
<td>28</td>
<td>2.13</td>
<td>0.05</td>
</tr>
<tr>
<td>Greenwaste biochar 5 t/ha</td>
<td>450</td>
<td>100</td>
<td>2.13</td>
<td>0.05</td>
</tr>
<tr>
<td>Greenwaste biochar 10 t/ha</td>
<td>416</td>
<td>76</td>
<td>2.10</td>
<td>0.1</td>
</tr>
<tr>
<td>Control</td>
<td>433</td>
<td>76</td>
<td>2.00</td>
<td>0.05</td>
</tr>
<tr>
<td>Lime 1.5 t/ha</td>
<td>416</td>
<td>76</td>
<td>2.00</td>
<td>0.10</td>
</tr>
</tbody>
</table>

**Conclusions**

- The research trials to-date have shown that the slow pyrolysis of sugarcane bagasse and cane trash can provide the energy to generate 1 MWh for each two tonnes of dry material. Cane trash, a material potentially problematic during co-generation was shown to be an ideal feed-stock for slow pyrolysis.
- The research shows that the majority of the nutrients in the cane feedstocks are retained in the biochar; thus can be returned to the field along with the carbon.
- Biochar from trash and bagasse had low molar H/C ratios indicating their aromaticity and hence long-term stability in soils.
- A significant reduction in the emissions of nitrous oxide from soil was shown following the application of varying biochar products.
- This manuscript has demonstrated numerous benefits for the Australian and international sugarcane industry. Field scale assessment of this technology is warranted as significant economic, environmental and climate outcomes may be achieved.
Acknowledgements

We would like to acknowledge the efforts and contribution of Richmond Land Care Inc. and The Northern Rivers Catchment Authority for their support of the project. The Australian Government for their support by funding the research through their Caring for Our Country projects. The project also acknowledges the Burdekin Bowen Integrated Floodplain Management Advisory Committee.

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LE ROLE DU BIOCHARBON DANS LA GESTION DE LA CANNE A SUCRE

Par

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Résumé

Dans de nombreuses parties du monde, l’industrie sucrière à base de canne à sucre produit à la fois des denrées et de l’énergie. Cette industrie procure une diminution des gaz à effet de serre et une atténuation du changement climatique. Par un procédé de pyrolyse lente, la conversion thermique des résidus de canne tels que le paillis de récolte en vert et la bagasse peut produire à la fois une énergie supplémentaire thermique ou électrique et du biocharbon. Des études ont montré qu’une unité de pyrolyse lente pouvait générer plus de 3MWh d’électricité à partir de 4 tonnes de résidus secs ou 1.3 tonnes de biocharbon par heure. Le biocharbon a des caractéristiques similaires au carbone noir, et a été récemment proposé comme voie de séquestration pour éliminer à long terme le CO2 de l’atmosphère, à cause de sa structure chimique stable. Le biocharbon provenant d’une tonne de bagasse pourrait séquestrer environ 2.3 tonnes d’équivalents CO2. En plus de la séquestration de C, le biocharbon a d’autres avantages incontestables tels que l’amélioration de la qualité du sol, de la CEC, de la rétention en eau etc. Il a aussi la capacité de réduire les émissions de gaz à effet de serre provenant du sol, tels que l’oxyde nitreux et le méthane. Des biocharbons provenant des résidus de canne et de bagasse ont été incubés dans des sols du Burdekin en Australie afin de tester les réductions de gaz à effet de serre. Des applications de 10 t/ha de biocharbon de bagasse ont diminué significativement les émissions de gaz à effet de serre comme l’oxyde nitreux (N\(_2\)O) provenant de sols fertilisés avec de l’urée. La performance agronomique du biocharbon a été évaluée dans un essai de 15 parcelles conduit dans une exploitation de la Tweed Valley, NSW. Des biocharbons de détritus, de papeterie et de déchets verts ont été testés. Les témoins incluaient des traitements chaulés. Chaque parcelle était constituée de 3 rangs de canne de 30 m pour permettre la récolte à l’échelle commerciale. Bien qu’aucun effet significatif sur le rendement ne fût observé l’année 1, cet essai doit continuer sur deux cycles supplémentaires pour estimer les effets sur le rendement. Le biocharbon a été inclus dans l’agenda de la conférence de 2012 sur le climat à Copenhague, comme un moyen de séquestrer à long terme le carbone et comme remède sur les terres dégradées pour la production alimentaire et la reforestation. Notre travail est de démontrer que l’utilisation de biocharbon dans l’industrie sucrière peut potentiellement fournir 1) de l’énergie renouvelable, 2) un revenu à partir des déchets, 3) une atténuation du changement climatique au travers de la stabilisation du carbone, 4) une atténuation du changement climatique au travers de la réduction des émissions de CO\(_2\) du sol et 5) une amélioration de la fertilité du sol et des performances agronomiques.
EL PAPEL DEL BIOCARBÓN EN EL
MANEJO DE LA CAÑA DE AZUCAR

Por

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PALABRAS CLAVE: Biocarbón, Pirólisis, Energía,
Fertilidad del Suelo, Gas de Efecto Invernadero (GEI).

Resumen

En muchas partes del mundo la industria de la caña de azúcar produce alimentos y energía (estacionaria y combustible). La industria está bien posicionada para ofrecer reducción de los gases de efecto invernadero y mitigación del cambio climático. La conversión térmica de residuos de caña tales como residuos del corte en verde y bagazo, a través de un proceso de pirólisis lenta, puede producir energía térmica o eléctrica adicional, así como biocarbón. Los estudios han demostrado que una unidad comercial de pirólisis lenta podría generar más de 2MWh de electricidad de cada cuatro toneladas de basura seca, así como 1.3 toneladas de biocarbón por hora. El biochar tiene características similares a las del carbón vegetal, y recientemente ha sido sugerido como una forma viable para fijar CO₂ de la atmósfera a largo plazo - debido a su estructura química muy estable. Una tonelada de biocarbón derivado de bagazo fijaría carbono en el orden de 2.3 toneladas equivalentes de CO₂. Además de la fijación de carbono, el biocarbón ofrece otros beneficios importantes tales como mejoras de la calidad del suelo, de la CIC, retención de la humedad etc. También tiene el potencial para reducir las emisiones de gases de efecto invernadero, incluidos el óxido nitroso y el metano, desde los suelos de caña. Se realizaron estudios de incubación de suelos de la región de Burkedin en Australia a los cuales se les aplicó biocarbón derivado de residuos de caña y bagazo para demostrar la reducción en la emisión de gases de efecto invernadero. Encontramos reducción significativa de la emisión del gas de efecto invernadero, óxido nitroso (N₂O), desde un suelo fertilizado con urea al cual se le aplicó biocarbón de bagazo a una dosis de 10 t/ha. El comportamiento agronómico del biocarbón está siendo evaluado en un ensayo de 15 parcelas realizado en una propiedad con caña de azúcar en Tweed Valley, NSW. Se incluyeron biocarboines de fábrica de papel y de residuos verdes de caña. Los controles incluyeron tratamiento de encalado. Cada parcela fue compuesta por 3 surcos de caña de 30 m de longitud para permitir la cosecha a escala comercial. Aunque no se registraron efectos significativos en el rendimiento durante el año 1, se espera que este ensayo continúe durante dos temporadas más permitiendo obtener datos adicionales que permitan demostrar los efectos sobre el rendimiento. El biocarbón se ha incluido en la agenda del protocolo de Copenhague 2012 como una forma de fijación de carbono a largo plazo, y para rehabilitación de tierras degradadas que se destinarían a la producción de alimentos y la reforestación. Nuestro trabajo está demostrando que la implementación de la pirólisis lenta y la utilización del biocarbón en la industria de la caña de azúcar tiene potencial para proveer 1) energía renovable 2) ganancia a partir de residuos 3) mitigación del cambio climático a través de la estabilización del carbono 4) mitigación del cambio climático a través de la reducción de emisiones de N₂O desde el suelo, y 5) mejoramiento de la fertilidad del suelo y del rendimiento agronómico.
SUGARCANE ROOT SYSTEM DEPTH
IN THREE DIFFERENT COUNTRIES

By

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KEYWORDS: Brazil, Côte d'Ivoire, Réunion, Root System, Sugarcane Root Front.

Abstract

THE SUGARCANE root system depth is crucial as it determines the potential depth of soil available for water and nutrient uptake by the crop. It was reported in an early publication that these roots could grow quite deep (6 m), but otherwise very little data are available on the root system depth. The present study was carried out in three countries: Côte d'Ivoire (var. NCo376), Brazil (var. RB72454) and Réunion, France (var. R570) at various sugarcane growth stages. There were no shoot or root growth constraints (deep soil with enough water). For plant cane, the root front growth (RF in cm) was linear. In Côte d'Ivoire, from 45 to 160 days after planting (DAP), RF = 0.81 DAP; R² = 0.91. On the island of Réunion, from 100 to 280 DAP, sugarcane root front growth was: RF = 0.56 DAP; R² = 0.70. When DAP was replaced by thermal time (TT: sum of degree-days), the root front growth patterns were quite similar in Réunion and Côte d'Ivoire (RF = 0.045 and 0.049 TT, respectively). In ratoon conditions, RF was stable when roots from the previous cycle were still in the soil at the onset of the cropping season. Thus, the observed root depth was approximately 4 m in Brazil and Réunion, even though the environment and cultivars were different. These findings showed that, when there is no marked crop growth constraint, roots of modern commercial sugarcane varieties can grow to depths of about 4 m in ratoon crops. While these values were lower than those reported in previous studies, they were higher than those generally accepted at present.

Introduction

The depth of the sugarcane root system determines the volume of soil available for water and mineral uptake. A review of recent results indicates that this depth is still not clearly established (Smith et al., 2005). Evans (1936) found that roots of old sugarcane varieties could grow to a depth of 6 m under very favourable conditions. These estimates have been partially challenged for modern varieties (Blackburn, 1984). Since the 1930s, no publication has reported sugarcane roots growing below a depth of 2 m. However, the rooting depth is a particularly useful factor for crop modelling and for fertilisation and irrigation decision-making. For example, modelling studies carried out by scientists in Réunion were based on a root system depth of about 1.5 m, as roughly estimated in some unpublished studies. The root system depth in live sugarcane plants is particularly hard to assess. Sugarcane plants grow again after the first plant sugarcane cropping season and the first shoot harvest, and the extent of time that the previous root system remains alive is not well-known. Moreover, to our knowledge, very few studies have been published on relationships between the environment (especially deep soil characteristics) and the root front depth.
The authors have pooled root depth findings from three different environments in Brazil, Côte d’Ivoire and Réunion. The aim of this study was to combine these results in order to estimate the root system depth in these three ecosystems so as to come up with more precise root front depth values to be used in decision support tools and crop models. Sugarcane root front data are also essential for determining nutrient and water balances and subsequently identifying the soil limit zone where nutrients switch from being fertilisers to becoming potential groundwater pollutants.

Material and methods

Experimental design, environments and treatments

Studies were carried out at three sites located very far apart: Côte d’Ivoire (Africa), Brazil and Réunion (Indian Ocean), within the framework of agronomic research programs under way to investigate several parameters including the sugarcane root front. There were thus some methodological variations between experiments. The experimental site in Côte d’Ivoire was located at Bouaké (7°40N, 5°5W, 350 m elevation) in a deep (> 2 m) sandy clay oxisol with a high gravel content ranging from 25% in the surface horizon to 50% at depths below 1 m. The soil bulk densities differed very little at the Réunion and Brazil sites, at least in unaltered soils (Table 1). The markedly higher bulk densities in Côte d’Ivoire were due to the presence of coarse elements with bulk density of about 2.7 Mg/m$^3$, but the fine soil structure was favourable for root growth. In Brazil, the experiments were conducted at Londrina University (23°2S, 51°1W, 560 m elevation) in a very deep clayey red eutroferric latosol without gravel. In Réunion, the experimental site was located at Saint Pierre in the southern part of the island (21°S, 55°E, 250 m elevation) in a deep (over 5 m) clayey cambisol, free of coarse elements as in Brazil, but with a lower soil structure quality. The Côte d’Ivoire study was carried out in 1994, but the findings were never published. The Brazilian study was conducted in 2005 and 2006, while in Réunion it was carried out in 2007, 2008 and 2009.

Table 1—Bulk density at the three sites. At the Réunion site: unaltered soil (control) and soil removed from the surface to 2 m depth and put back 4 years earlier.

<table>
<thead>
<tr>
<th>Depth(cm)</th>
<th>Côte d’Ivoire</th>
<th>Brazil</th>
<th>Réunion</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–40</td>
<td>1.52</td>
<td>1.02</td>
<td>1.15</td>
</tr>
<tr>
<td>40–80</td>
<td>1.68</td>
<td>1.00</td>
<td>1.12</td>
</tr>
<tr>
<td>80–120</td>
<td>1.63</td>
<td>0.98</td>
<td>1.17</td>
</tr>
<tr>
<td>120–200</td>
<td>1.60</td>
<td>0.97</td>
<td>1.17</td>
</tr>
<tr>
<td>200–400</td>
<td>0.97</td>
<td>1.23</td>
<td>1.23</td>
</tr>
</tbody>
</table>

The three sites have a tropical (Côte d’Ivoire, Réunion) or subtropical (Brazil) climate. Rainfall (with supplementary irrigation in Réunion and Côte d’Ivoire) was sufficient for normal crop growth, particularly for the development of deep roots. During the study periods, mean air temperatures were: 28.4°C, 21.9°C and 23.2°C in Côte d’Ivoire, Brazil and Réunion, respectively, with mean temperatures always above 16°C/d. The sugarcane varieties (NCo376 in Côte d’Ivoire, RB72454 in Brazil and R570 in Réunion) were representative of varieties grown by farmers. The cropping systems were conventional and tailored to local conditions. Spacing between rows was 1.5 m (Côte d’Ivoire and Réunion) or 1.4 m (Brazil). Plant sugarcane only was studied in Côte d’Ivoire, whereas only a ratoon crop was studied in Brazil. In Réunion, the study concerned both plant sugarcane (in 2006 and 2009) and ratoon crops (2007 and 2008). In 2009, plant sugarcane root systems were studied in an area of the site where the soil had been altered (removed and put back)
up to 2 m in depth for soil studies 4 years earlier. The soil put back in each soil horizon was similar to the surrounding soil, except that it remained looser (Table 1). There were thus three treatments in Réunion: plant sugarcane in unaltered and altered soil and a ratoon crop.

**Root depth study: dates, methods, replications**

In Côte d’Ivoire, the study was carried out at three different dates: 45, 113 and 160 days after planting (DAP) using the monolith method (Lee, 1927). Each monolith had the following dimensions: length 0.25 m, width 0.2 m, thickness 0.2 m, with five replications. In Brazil, the ratoon crop root fronts were estimated with the trench profile technique (Chopart et al., 2008a, 2009) adapted from Böhm (1976). The trench profiles were 2 m wide and as deep as the root front. The maximum root depths were measured directly in the field. The study was carried out at 240 and 300 days after ratoon (DAR) with six replications at each measurement date. In Réunion, the plant sugarcane study was performed with the rhizotron (Van de Gien et al., 1994) and the trench profile techniques. Vertical rhizotrons were 1.5 m wide and 1.4 m deep. Measurements were thus limited to the period when the root depth was less than 1.4 m. For plant and ratoon sugarcane, the trench profiles were 1.5 m wide, with depths varying according to the root front. The intersections between the trench profile and the roots were counted and mapped. This made it possible to assess the root length density (RLD) distributions in the profile (Chopart et al., 2008b, 2009). In addition, about 10 cm of soil was removed in the profile at the root front level to monitor the presence or absence of roots in these samples in the field. The soil profiles were about 4.5 m deep. In plant sugarcane, root fronts were studied in two rhizotrons at nine dates and with the trench profile technique at eight dates with one to three replications. The ratoon sugarcane study was carried out on a single date between 235 and 245 DAR, with six replications. Correlations were determined between the crop age and the root front depth. For a better comparison of the results at the various sites, the time from planting or ratoon date was also expressed as a sum of each day’s mean temperature (sum of degree-days[SDD]) above the sugarcane baseline temperature (estimated to be 12°C).

After planting, roots grow from cuttings (sett roots) buried 10 to 20 cm deep. After a few days, shoot roots grow from the first nodes on the new stalks, close to the surface (van Dillewijn (1952). Analysis of these complex rooting dynamics that take place during the first days of the plant cropping season was beyond the scope of the present study. Measurements were first recorded 45 DAP in Côte d’Ivoire or even later in Réunion (70 DAP), once the root system grown from the year’s shoots predominated over the initial system grown from cuttings. To simplify the analysis and future use of the results, regressions between the crop age (or thermal time) and the root front depth were thus assigned a 0 cm y-coordinate on the planting day (DAP = 0). The established relationships were valid only within the range of the measured results, from around 50 DAP.

**Results**

**Plant sugarcane (Côte d’Ivoire and Réunion)**

In Côte d’Ivoire, the root front depth progressed linearly from 45 DAP to 160 DAP, i.e. a growth rate of about 0.8 cm/day (Figure 1A). In Réunion, with the rhizotron technique, plant sugarcane root front growth was also linear between 70 and 170 DAP (Figure 1B), at a rate of approximately 0.7 cm/day. After 170 DAP, the rhizotron, whose depth was limited to 140 cm, could no longer be used. Outside of the rhizotrons, the root front growth rate measured with the trench profile method was approximately 0.56 cm/day, i.e. slightly lower than that noted in the rhizotron (Figure 1C). The difference seemed to be due to the fact that roots were in a relatively less constrained environment against the rhizotron glass panel and could thus grow at a slightly more vertical angle. The results obtained in the rhizotron and through the trench profile technique were complementary. With the rhizotrons, the measurements were obtained more frequently but in somewhat artificial conditions. Data obtained by the trench profile technique were representative of the root front in natural conditions but, as the measurements were more time consuming and costly, they were less numerous. The rhizotron findings confirmed that the root front growth was linear.
The trench profile technique made it possible to assess the growth rate in unaltered soil which was representative of the local soil, i.e. between 0.55 and 0.6 cm/day.

In Réunion, after 170 DAP, root front growth (measured by the trench profile technique only) continued at a constant rate until the end of the study (265 DAP). In the same year, at the same site, but in a soil that was decompacted 4 years earlier and whose bulk density and mechanical resistance to penetration remained lower, the root front was deeper: 200 cm 220 DAP, i.e. 0.9 cm/day (Figure 1C). In unaltered soil, the root front reached 170 cm in only one profile (at 187 DAP). In Réunion, in natural conditions, the mean root front growth rate was 0.55 to 0.6 cm/day.

The growth rate reached as high as 0.9 cm/day when the soil physical conditions were particularly favourable, or when the soil was tilled very deeply some years before measurement. Root front between 280 DAP and harvest (360 DAP) is still being studied. Decreased growth has been observed at the end of the cycle in other tropical crops such as pearl millet and sorghum (Chopart, 1985).

It is therefore quite probable that sugarcane root front growth will not increase during its final stage. We can tentatively assume that in Réunion the plant sugarcane root front depth would be approximately 2 m at harvest. When thermal time was used instead of DAP, the root front growth rates observed in Côte d’Ivoire and Réunion, where the weather is slightly less hot, were closer than rates expressed in number of DAP (Figure 1).

Côte d’Ivoire
Root depth (cm) = –0.049 TT
R² = 0.91
n = 31

Réunion
Root depth (cm) = –0.045 TT
R² = 0.67
n = 14

TT: Thermal time (degree-days above 12°C)

This showed the influence of temperature on root front growth in relation to shoot growth, which was also higher. There was still a slight difference, which could be explained by several factors (varieties, soil characteristics, study methods); however, none of these parameters had a major impact.

Ratoon sugarcane (Réunion and Brazil)

In Brazil, in 3rd year and 4th year ratoon sugarcane, the maximum root system depth levelled off between 240 and 300 DAR (Table 2). The soil tillage method used when the sugarcane crop was planted 4 years earlier (between 0 and 30 cm deep) had no effect on the root front depth (data not shown), which was approximately 4 m, with 6 replications on average. In Réunion, at the same cycle stage the mean depth in the 6 replications was 3.70 m (Table 2).
Table 2—Maximum ratoon sugarcane root depth in Brazil and Réunion (mean, standard deviation, highest and lowest root front of 6 replications at both Brazil and Réunion) observed on measurement dates with some related characteristics.

<table>
<thead>
<tr>
<th></th>
<th>Brazil</th>
<th>Réunion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sum Temp in °C &gt;12</td>
<td>2700</td>
<td>3000</td>
</tr>
<tr>
<td>DAR</td>
<td>270</td>
<td>260</td>
</tr>
<tr>
<td>Millable yield (kg/m²)</td>
<td>10</td>
<td>9.4</td>
</tr>
<tr>
<td>Mean maximum depth (m)</td>
<td>4.0</td>
<td>3.7</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.20</td>
<td>0.43</td>
</tr>
<tr>
<td>Highest value (m)</td>
<td>4.3</td>
<td>4.1</td>
</tr>
<tr>
<td>Lowest value (m)</td>
<td>3.7</td>
<td>3.1</td>
</tr>
</tbody>
</table>

2-D mapping of the root distribution was carried out with the method used in Réunion (trench profile technique, root intersection mapping and root length density from root intersection; Chopart et al., 2008a, b, 2009). In the deepest profile (Figure 2A), the root distribution was very irregular at deep horizons where roots took advantage of soil areas with lower resistance in order to progress vertically. This was not as clear in the less deep profile (Figure 2B). Roots that grew vertically had large diameters, but they had the same appearance and internal structure as roots of the same diameter that were less vertical, or horizontal.

![Fig. 2—Ratoon sugarcane in Réunion: 2-D root length density (cm/cm³) distribution in a 1.5 m large profile. A: deepest profile among the four studied profiles, and B: least deep profile.](image)

Very similar results were obtained in Réunion and Londrina (Brazil), although they were obtained with two different varieties and at sites that were far apart, despite the slightly lower
temperatures in Brazil. However, the sites shared some similar characteristics, including deep soil with low density and resistance to penetration, and variable soil moisture but which was always sufficient to ensure root growth. The 4-m root depth was inferior to the 6-m depth obtained by Evans (1936), but deeper than is generally accepted for sugarcane root systems.

Discussion and conclusion

No definitive conclusion could be drawn on the basis of the results obtained in three countries concerning plant sugarcane and ratoon sugarcane root system depths. However, they provided greater insight into sugarcane root system depths in the studied environments. In particular, in deep moderately compact soils, the root front growth rate was constant after the shooting and root system development stage, i.e. approximately 0.55 cm/day with a maximum of 0.9 cm/day under very favourable conditions (soil tilled to a depth of 2 m four years earlier). These results obtained in very well structured soil up to 2 m deep could explain the particularly spectacular findings of Evans, i.e. 6 m deep roots in ratoon sugarcane.

The marked variation noted in Réunion between the root system depth in the second part of the plant sugarcane cycle (under 2 m) and that observed roughly at the same cycle stage in a 5th year ratoon sugarcane (4 m) suggests that the root front grows deeper from year to year between plant sugarcane and ratoon crops in Réunion. If this is the case, the roots (at least the deepest ones) could remain alive long after the sugarcane crop has been harvested and deeper parts of the root system could sprout new roots during the following growing season. This still has to be confirmed, in particular by studying the root system depth throughout several sugarcane growing seasons in the field with various soil penetration resistance levels. This would be laborious work but the findings could be highly interesting for modelling sugarcane water uptake and growth under water stress conditions in plant or ratoon sugarcane with various numbers of ratoon cycles.

REFERENCES

PROFONDEUR DU SYSTEME RACINAIRE DE LA CANNE A SUCRE DANS TROIS PAYS DIFFERENTS

Por

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MOTS CLES: Brésil, Côte d’Ivoire, Réunion, Système Racinaire, Front Racinaire de la Canne à Sucre.

Résumé

La profondeur du système racinaire de la canne à sucre est un paramètre important car elle détermine la profondeur potentielle du sol utile pour l’alimentation hydrique et minérale de la culture. Il a été reporté, dans une publication ancienne, que le système racinaire de la canne à sucre peut atteindre une profondeur de 6 m, mais peu de données récentes sont disponibles sur la profondeur du système racinaire de cette culture. L’étude a été menée dans trois pays: Côte d’Ivoire (var. NCo376), Brésil (var. RB72454) et Réunion, France (var. R570), à différents stades de végétation de la canne à sucre. Il n’y a pas eu de contraintes majeures à la croissance racinaire (sols profonds, avec une humidité suffisante). Pour une canne vierge, la croissance du front racinaire (RF, en cm) a été linéaire, de 45 à 160 jours après plantation (DAP) : RF = 0.81 DAP; R² = 0.91. A la Réunion, le front racinaire de la canne à sucre a été : RF = 0.56 DAP; R² = 0.70, de 100 à 280 DAP. Si l’on remplace DAP par le temps thermique (TT : somme des degrés-jours), les niveaux de croissances des fronts racinaires deviennent alors proches à la Réunion et en Côte d’Ivoire (RF= 0.045 et 0.049 TT, respectivement). En repousse, RF a été stable, les racines du cycle précédent restant encore dans le sol en début de cycle. La profondeur racinaire observée a été de 4 m au Brésil et à la Réunion, dans des environnements pourtant très différents. Ces résultats montrent que, en absence de contraintes marquées à la croissance racinaire, les racines des variétés modernes peuvent atteindre 4 m en repousse. Bien que ces valeurs soient plus faibles que celles avancées dans des travaux anciens, elles sont supérieures à celles généralement admises actuellement.

PROFUNDIDAD DEL SISTEMA RADICULAR DE LA CAÑA DE AZUCAR EN TRES DIFERENTES PAISES

Por

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PALABRAS CLAVE: Brasil, Costa de Marfil, Reunión, Sistema de raíz, Frente de raíz de la Caña de Azucar.

Resumen

La profundidad del sistema radicular de la caña de azúcar es crucial pues determina la profundidad del suelo disponible para la absorción potencial de agua y nutrimentos por parte del cultivo. En una publicación anterior a esta se reportó que las raíces podrían crecer muy profundas (6 m), pero por otra parte, hay disponible muy poca información sobre la profundidad del sistema radicular. El presente estudio fue realizado en tres países: Costa de Marfil (variedad NCo376), Brasil (variedad RB72454) y Réunion, Francia (variedad R570) en diferentes etapas de crecimiento de la caña de azúcar. No hubo impedimentos para el crecimiento de la parte aérea o de la raíz (suelo profundo con suficiente humedad). En la plantilla, el frente de crecimiento de la raíz (RF en cm) fue
lineal. En Costa de Marfil de 45 a 160 días después de la siembra (DAP), RF = 0.81 DAP; R² = 0.91. En la isla de Réunion, de 100 a 280 DAP, el frente de crecimiento las raíces de la caña de azúcar fue: RF = 0.56 DAP; R² = 0.70. Cuando DAP fue substituido por tiempo térmico (TT: suma de grados-día), los patrones del frente de crecimiento del sistema radicular fueron similares en Réunion y Costa de Marfil (RF = 0.045 y 0.049 TT, respectivamente). En condiciones de soca, al inicio del nuevo ciclo del cultivo y cuando las raíces del ciclo anterior todavía estaban en el suelo, el RF fue estable. De esta forma, la profundidad observada de la raíz fue de aproximadamente 4 m en el Brasil y Réunion, aunque el ambiente y los cultivares fueron diferentes. Estos resultados demostraron que, cuando no hay impedimento para el crecimiento del cultivo, las raíces de las variedades comerciales modernas de caña de azúcar pueden alcanzar profundidades de casi 4 m en socas. A pesar de que estos valores fueron menores que los reportados en estudios anteriores, fueron mayores que los actualmente aceptados.
FUNCTIONAL RELATIONSHIP BETWEEN SUGARCANE ROOT BIOMASS AND LENGTH FOR CROPPING SYSTEM APPLICATIONS

By

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KEYWORDS: Specific Root Length, Root Length Density, Root Model, Réunion, Côte d’Ivoire.

Abstract

Sugarcane root length density (RLD, m/m³) and root biomass are key characteristics for respectively determining: (i) the crop nutrient and water uptake capacity, and (ii) carbon partitioning in plants and balance in soil. In previous studies, often only one of these parameters was measured. It is therefore useful to link the RLD and root biomass density (RBD, g/m³) to evaluate one parameter in relation to the other. Relationships between RLD and RBD and specific root length (SRL, m/g) were studied in Côte d’Ivoire and Réunion. Mean SRLs of fine roots were independent of the root location in the soil profile and plant age but higher in Côte d’Ivoire (68 m/g, SD = 19) than in Réunion (35 m/g, SD = 10). The best fit between the RBD and RLD of thick roots was a power function (RLD = 21.3 RBD⁻¹.⁷⁴⁵; R² = 0.⁸⁵). Mean SRL was 7 m/g. When all roots were studied together, the best fit between RBD and RLD was also a power function, with little variation between the two sites or between plant and ratoon sugarcane. The fits calculated with all data except those obtained very close to the plant stem were: RLD = 85.⁵ RBD⁻¹.⁷⁴² (R² = 0.⁸⁸) and mean SRL = 27 m/g (SD =13). Relationships between root length and biomass were neither fixed nor fully random. Due to SRL variability, it was hard to pinpoint any mechanistic links between root length and biomass. Conversely, for simple field evaluations, a rough and ready RLD estimate can be made on the basis of RBD, and vice-versa.

Introduction

Sugarcane root length density (RLD) and root biomass are key characteristics for respectively determining: (i) the crop nutrient and water uptake capacity, and (ii) carbon partitioning in plants and balance in soil. In previous studies, often only one of these parameters was measured, depending on the study objectives and methods used.

Root biomass cannot be evaluated directly with minirhizotron methods (Box, 1996) or different trench profile techniques (Böhm, 1976; Vepraskas, 1988; Chopart, 1999; Chopart et al., 2008) that are focused on RLD evaluation. On the other hand, conventional methods involving soil cores and monoliths (Lee, 1927), in which roots are removed from soil, can be used to measure dry weight easily, whereas RLD measurement is a substantially longer operation that is seldom performed for want of time.

Several sugarcane crop models such as CANEGRO (Inman-Bamber, 1991) or APSIM (McCown et al., 1996) used to model root biomass production require a link between the root biomass density (RBD) and RLD. However, little is currently known about the relationship between root weight and length or evaluation of the specific root length (SRL, in m/g). Initial studies on sugarcane indicated that SRL ranged from 6 to 23 m/g, with a mean of around 18 m/g in Brazil.
(Ball-Coello et al., 1992). Other authors (van Antwerpen et al., 1993) obtained substantially lower values in South Africa: around 3 to 5 m/g for plant sugarcane aged 50–180 days after planting (DAP).

This study was carried out to gain further insight into the relationship between root weight and length in plant and ratoon sugarcane, for both fine and thick roots, while focusing only on identifying simple and functional relationships without any deterministic motives. To our knowledge, this is the first root type-based study that has been carried out on sugarcane crops grown in commercial plantation conditions.

Material and methods
Experimental design, environments and treatments
The studies were carried out at two sites: Côte d’Ivoire (Africa) and Réunion (Indian Ocean). The experimental site in Côte d’Ivoire was located at Bouaké (7°40′N, 5°5′W, 350 m elevation) in a deep (> 2 m) sandy clay oxisol with high coarse element (> 2 mm) contents ranging from 25% in surface horizons to 50% below 1 m. In Réunion, the experimental site was located at Saint-Pierre in the southern part of the island (21°S, 55°E, 250 m elevation) in a deep (over 5 m) clayey cambisol without any coarse elements.

The climate was tropical at both sites. Rainfall (with supplementary irrigation) was sufficient for normal plant growth, especially deep root growth. Varieties under study, namely NCo376 in Côte d’Ivoire and R570 in Réunion, were representative of sugarcane varieties grown by farmers. Conventional cropping systems (tillage, fertilisation, 1.5 m inter-row spacing) were used.

In Côte d’Ivoire, the study was focused on plant sugarcane at two dates (45 and 113 DAP), with measurement depths up to the root front (0.4 m and 1.1 m at 45 and 113 DAP, respectively). In Réunion, the study was undertaken on both plant sugarcane (four replicates, maximum measurement depth 0.8 m) and ratoon crops (eight replicates, maximum measurement depth 1.2 m).

In Réunion, roots were sampled in the soil using the soil core technique with 251 cm³ metal cylinders. In Côte d’Ivoire, the monolith method used was very similar to the soil core method, but with larger sample volumes (0.2 × 0.2 × 0.25 m) and no replication. At both sites, samples were obtained at three horizontal distances along the sugarcane row: 0–0.25 m, 0.25–0.50 m and 0.5–0.75 m and at several depths, in 0.2 m steps in Côte d’Ivoire and 0.1 m steps in Réunion. Roots were separated from the soil by sieving (1 mm mesh).

Non-root organic fragments were carefully removed. Roots were separated into two subsamples: fine and thick. We decided to set the diameter boundary at 1 mm because our non-quantitative observations suggest that shoot-born roots have a diameter > 1 mm and most other lateral roots have a diameter < 1 mm. Separation (handmade and with a blade) between the two types of roots was made by visual evaluation. A few fine roots could not be entirely separated from thick roots, but the effect on the specific root length of thick roots samples remained very low. Roots were dried (60°C; 24 h) and weighed separately. Their respective lengths were evaluated using the intersection method (Newman, 1966) modified by Tennant (1975).

Analysis
Relationships between RBD and RLD were investigated by regression analysis of samples distributed throughout the soil profile at various vertical and horizontal distances. All sample SRLs were analysed (mean and standard deviation). We tried to establish links between root sample SRL variability and parameters that are easy to recognise in the field, especially their location in the profile: depth or distance from the stem base (DP).

DP is the diagonal between the depth and horizontal distance. The initial analysis revealed that roots located immediately under the stem or row had a very high RBD, often—but not always—with a high proportion of thick roots. Roots located immediately under the sugarcane row between 0 and 0.2 m depth and 0.25 m on each side of the row were thus analysed separately. It was
specified when the results concerned roots close to the stem base, otherwise the roots were located elsewhere. Some samples contained no thick or fine roots, which accounts for the differences noted between the number of pooled root samples and samples with thick and fine roots separated.

Results

Fine root sample analyses (< 1 mm diameter)

In Réunion, linear regressions were obtained between the fine root weight and length for plant and ratoon sugarcane at 113 DAP (Figure 1A, Tables 1 and 2). The SRL did not depend on the sample location in the soil. The SRL determined for plant and ratoon sugarcane roots was 35 m/g (Table 2). Between-sample SRL variability seemed random. In Côte d’Ivoire, the fine root SRL was higher than in Réunion (Table 2).

![Fig. 1—Relationships between the root biomass density (RBD) and root length density (RLD) at the Réunion site with plant sugarcane and ratoon crop. A: fine roots (Ø <1 mm). B: thick roots (Ø >1 mm).]

Table 1—Features of linear regressions between the root biomass density (g/m³) and root length density (m/m³) in Réunion. Regressions were arbitrarily given an intercept of 0.

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Number of samples</th>
<th>Slope</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine roots</td>
<td>Plant cane</td>
<td>64</td>
<td>29.4</td>
</tr>
<tr>
<td></td>
<td>Ratoon cane</td>
<td>44</td>
<td>31.3</td>
</tr>
<tr>
<td></td>
<td>Plant &amp; ratoon cane</td>
<td>108</td>
<td>30.5</td>
</tr>
<tr>
<td>Thick roots</td>
<td>Plant cane</td>
<td>43</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>Ratoon cane</td>
<td>31</td>
<td>4.1</td>
</tr>
<tr>
<td></td>
<td>Plant &amp; ratoon cane</td>
<td>74</td>
<td>4.1</td>
</tr>
</tbody>
</table>

Table 2—Specific root length (m/g) of roots in Réunion, Côte d’Ivoire and both sites together. (SD: standard deviation).

<table>
<thead>
<tr>
<th>Specific root length</th>
<th>Sites</th>
<th>Number of samples</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine roots</td>
<td>Réunion</td>
<td>108</td>
<td>35.4</td>
<td>10.1</td>
</tr>
<tr>
<td></td>
<td>Côte d’Ivoire</td>
<td>26</td>
<td>68.1</td>
<td>18.8</td>
</tr>
<tr>
<td></td>
<td>All</td>
<td>134</td>
<td>41.7</td>
<td>17.8</td>
</tr>
<tr>
<td>Thick roots</td>
<td>Réunion</td>
<td>74</td>
<td>6.9</td>
<td>3.7</td>
</tr>
<tr>
<td></td>
<td>Côte d’Ivoire</td>
<td>28</td>
<td>7.0</td>
<td>3.7</td>
</tr>
<tr>
<td></td>
<td>All</td>
<td>102</td>
<td>7.0</td>
<td>3.7</td>
</tr>
<tr>
<td>All roots</td>
<td>Réunion</td>
<td>108</td>
<td>27.1</td>
<td>13.0</td>
</tr>
<tr>
<td></td>
<td>Côte d’Ivoire</td>
<td>28</td>
<td>26.7</td>
<td>13.3</td>
</tr>
<tr>
<td></td>
<td>All</td>
<td>136</td>
<td>27.0</td>
<td>13.0</td>
</tr>
</tbody>
</table>
Thick roots

In Réunion, relationships between the thick root weight and length in plant and ratoon sugarcane were a power function (Figure 1B and Eq. 1):

\[
\text{RLD} = 21.3 \text{RBD}^{0.724} \quad R^2 = 0.85 \quad n = 74 \quad (1a)
\]

\[
\text{RBD} = 0.0482 \text{RLD}^{1.2} \quad R^2 = 0.85 \quad n = 74 \quad (1b)
\]

SRL was therefore not fixed. According to the equation (Eq. 1), it ranged from 9.3 to 2.6 m/g when the RBD ranged from 20 to 2 000 g/m³. However, for simple estimates, a linear relationship could be assumed between the root weight and length. The mean SRL obtained from the pooled SRLs was thus 7 m/g, but with a high standard deviation of 3.7 (Table 2).

All roots (thick and fine)

Relationships between root weight and length in plant sugarcane and ratoon crops in Réunion (Figure 2) showed that: (i) the plant sugarcane and ratoon crop results were very close, (ii) in both cases, the best fit was a power function (Eq. 2). This equation was used to evaluate the root length according to weight, and the symmetrical equation was used to determine the RBD on the basis if the RLD:

\[
\text{RLD} = 85.5 \text{RBD}^{0.742} \quad R^2 = 0.88 \quad n = 108 \quad (2a)
\]

\[
\text{RBD} = 0.0097 \text{RLD}^{1.18} \quad R^2 = 0.88 \quad n = 108 \quad (2b)
\]

The nonlinearity of the relationship between RLD and RBD could have been partly due to a slight increase in SRL as the distance to the stem base increased. However, even when data obtained close to the root front were eliminated (very low RLD, under 80 cm for plant sugarcane), the relationship between the SRL (m/g) and the distance to the plant (DP, m) was not very close (SRL = 0.19 DP + 14; R² = 0.11; n = 118), indicating that DP was not the only SRL variation factor in the soil profile. However, this relationship could be used to take this slight influence of distance to the stem base into account when evaluating the SRL of pooled root samples.
Relationships determined between the root weight and volume in Côte d’Ivoire plant sugarcane were very close to those obtained in Réunion (data not shown). Côte d’Ivoire and Réunion SRLs were therefore pooled. SRLs were relatively stable at various root depths (Table 3), with a slight increase between 0.4 and 0.8 m depths, then a slight decrease from 1 m depth. For roots located less than 0.25 m below the stem base, the mean SRL calculated from the pooled SRLs was 16 m/g (SD = 6). It was 27 m/g for all other samples (Table 2).

Table 3—Mean specific root length (g/m³) at various soil depths for both sites (Réunion and Côte d’Ivoire) pooled. (SD = standard deviation).

<table>
<thead>
<tr>
<th>Depth</th>
<th>SRL (m/g)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–20 cm</td>
<td>25.2</td>
<td>12.2</td>
</tr>
<tr>
<td>20–40 cm</td>
<td>26.7</td>
<td>13.0</td>
</tr>
<tr>
<td>40–80 cm</td>
<td>29.8</td>
<td>13.0</td>
</tr>
<tr>
<td>80–120 cm</td>
<td>24.1</td>
<td>14.0</td>
</tr>
</tbody>
</table>

Discussion

The root system located less than 0.25 m vertically and horizontally under the stem base had a high but variable proportion of thick roots. SRLs in this area were clearly lower than those in other parts of the soil profile (approx. 16 m/g). These roots located under the stem base are not discussed hereafter. In Réunion, as in Côte d’Ivoire, fine root (Ø < 1 mm) SRL variability was not associated with easy-to-characterise explanatory factors such as depth, distance to the plant, crop age, etc., so this parameter seemed random.

A single SRL value was thus selected for this first stage of the analysis. SRL was clearly higher in Côte d’Ivoire than in Réunion. This difference was unexplained. It may have been due to factors related to the varieties or soils, which differed markedly: in Côte d’Ivoire, for instance, there was a substantial proportion of coarse elements of a few millimetres in diameter in the soil.

For thick roots, both in Côte d’Ivoire and in Réunion, the SRL increased with the distance from the plant—at least in the area between the row and 1.2 m away, i.e. increasing from under 3 m/g to approximately 9 m/g at 1 m depth. This was correlated with the larger root diameters near the stem base and with the presence of finer rank 2 roots in deep horizons. The root weight and length were linked by a power function.

For a simple evaluation, it was also possible to select a single value of 7 m/g for SRL of thick roots. A power function was also established between the root weight and length in the pooled root samples (all, thick and fine roots). However, the relationship was not very useful for predictions as the ratio between thick and fine roots could be variable.

To evaluate the root length on the basis of the root sample weight or vice-versa, it would be advisable to separate roots according to diameter. The root classification used in this study only very partially represents the sugarcane root system complexity, and the 1 mm limit between the two classes may seem arbitrary.

However, simplification was necessary to be able to take SRL differences in relation to measured root diameters into account and to be able to use SRL in crop models. The SRL of roots located immediately under the sugarcane stem and less than 25 cm from the stem core should also be assessed separately.

Some authors suggest values of 3–5 m/g (van Antwerpen et al., 1993) based on pot studies, while others report a very broad range of values, i.e. 6 to 26 m/g (Ball-Coello et al., 1992). The SRLs obtained were higher than those suggested by these authors. This difference could be due to environmental and genetic factors. It could also be due to the method used to calculate the mean
SRL based on a dataset containing highly variable RLD or RBD values, with an asymmetrical distribution. In this study, we decided to calculate the mean of SRLs, not the SRL from the mean length and the mean weight.

Conclusion

It seemed that the thick root SRL results obtained in Côte d’Ivoire and Réunion could be applicable in a broad range of conditions. However, the fine root SRLs obtained at both sites seemed to depend on the variety, physical environment or even genotype x environment interactions. It would be interesting to gain greater insight into the factors responsible for this variability. The fine root SRLs depended relatively little on the crop age and root location in the profile, which should facilitate future studies. The results obtained at both sites are not mechanistically representative of SRLs under all conditions, but they should be helpful for making rough and ready RLD estimations on the basis of RBD and vice-versa. They should also be useful for establishing better correlations and for modelling two agronomically and ecophysiologically important root functions: water and mineral uptake, and the carbon sink/source that the root system represents in the soil/crop system.

REFERENCES


RELATION FONCTIONNELLE ENTRE LA BIOMASSE ET LA LONGUEUR RACINAIRE DE LA CANNE A SUCRE POUR DES APPLICATIONS A L’ETUDE DES SYSTEMES DE CULTURE

Par

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MOTS CLES: Longueur Massique Racinaire, Longueur Racinaire Volumique, Modèle Racinaire, Réunion, Côte d’Ivoire.

Résumé

La longueur (RLD m/m\textsuperscript{3}) et la biomasse racinaires sont des paramètres clés pour déterminer respectivement : (i) les capacités d’alimentation hydrique et minérale, et (ii) la partition du carbone dans les plantes et le bilan de carbone dans le sol. Dans des études précédentes, très souvent, un seul de ces deux paramètres était mesuré. Il est donc utile de relier la RLD et la densité de biomasse racinaire (RBD) pour évaluer l’un des paramètres à partir du second. Des relations entre RLD et RBD et donc les longueurs massiques des racines (SRL) ont été étudiées en Côte d’Ivoire et à la Réunion. Les SRLs moyennes des racines fines n’étaient pas dépendantes de la localisation dans le profil et de l’âge de la culture, mais plus élevées en Côte d’Ivoire (68 m/g, SD = 19) qu’à la Réunion (35 m/g, SD = 10). Le meilleur ajustement entre la RBD et la RLD des grosses racines a été une fonction puissance (RLD = 21.3 RBD\textsuperscript{0.745}; \( R^2 = 0.85 \)), avec une SRL moyenne de 7 m/g. En étudiant toutes les racines ensemble, le meilleur ajustement est aussi une fonction puissance, avec peu de différence entre les deux sites et entre des cannes à sucre vierge ou en repousse. L’ajustement calculé avec toutes les données, sauf celles situées très près du pied, a été: RLD = 85.5 RBD\textsuperscript{0.742} (\( R^2 = 0.88 \)). En moyenne, la SRL = 27 m/g (SD=13). Les relations entre longueurs et poids racinaires n’ont été ni fixes ni complètement aléatoires. A cause de la variabilité de la SRL, il est difficile d’établir un lien mécaniste entre poids et longueur racinaire. Toutefois, pour des évaluations agronomiques simples, la RLD peut être estimée grossièrement sur la base de la RBD et vice versa.

RELACION FUNCIONAL ENTRE BIOMASA Y LONGITUD DE RAICES PARA APLICACIONES EN EL SISTEMA DE CULTIVO DE LA CAÑA DE AZUCAR

Por

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PALABRAS CLAVE: Longitud específica de raíces, Densidad de longitud de raíces, Modelo de raíces, Réunion, Costa de Marfil.

Resumen

La densidad de longitud de raíces (RLD, m/m\textsuperscript{3}) de la caña de azúcar y la biomasa de la raíz son características claves para determinar respectivamente: (i) la capacidad de la absorción de nutrimentos y agua del cultivo, y (ii) el partecionamiento de carbono en las plantas y su balance en el suelo. En estudios anteriores, a menudo solamente uno de estos parámetros fue medido. Por lo tanto es muy útil ligar la RLD y la densidad de biomasa de raíces (RBD, g/m\textsuperscript{3}) para evaluar cada
parámetro y su relación con el otro. Las relaciones entre RLD y RBD y longitud específica de raíz (SRL, m/g) fueron estudiadas en Costa de Marfil y Réunion. Las SRL’s de raíces finas fueron independientes de la localización de las raíces en el perfil de suelo y de la edad de planta pero mayores en Costa de Marfil (68 m/g, SD = 19) que en Réunion (35 m/g, SD = 10). El mejor ajuste entre RBD y RLD de raíces gruesas se logró con una función de potencia (RLD = 21.3 RBD$^*0.745$; $R^2 = 0.85$). La SRL promedio fue de 7 m/g. Cuando todas las raíces fueron estudiadas juntas, el mejor ajuste entre RBD y RLD fue también una función de potencia, con poca variación entre los dos sitios o entre plantilla y soja. Los ajustes calculados con todos los datos excepto aquellos obtenidos cerca de los tallos de las plantas fueron: RLD = 85.5 RBD$^*0.742$ (R$^2 = 0.88$) y el promedio de SLR = 27 m/g (SD=13). Las relaciones entre la longitud de la raíz y la biomasa no fueron fijas ni completamente aleatorias. Debido a la variabilidad de la SRL, fue difícil establecer claramente alguna relación entre longitud de raíces y biomasa. Por el contrario, para realizar evaluaciones simples en campo, se puede hacer una estimación aproximada y rápida de la RLD con base en la RBD, y viceversa.
OPPORTUNITIES FOR AND POTENTIAL CONSEQUENCES OF REDUCING NITROUS OXIDE EMISSIONS FROM SUGARCANE CROPS

By

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KEYWORDS: APSIM, Biofuel, Nitrous Oxide Emissions, Nitrogen Fertiliser, Sugarcane.

Abstract

USE OF nitrogen fertiliser is a major cause for increased atmospheric concentrations of nitrous oxide, a potent greenhouse gas. To reduce greenhouse gas emissions from sugarcane production, and so increase the crop’s attractiveness as a sustainable biofuel, it will be important to have a better understanding of nitrous oxide emissions and how they can be reduced. However, few measurements of nitrous oxide losses have been reported so far. Thus, our knowledge about nitrous oxide emissions from sugarcane production systems, and how they might vary in response to different environmental and management conditions, is limited. We compared measurements of nitrous oxide emissions with predictions from the cropping system model APSIM. We then simulated whole-of-crop nitrous oxide emissions over a range of environments and management practices in Australia. Predictions of nitrous oxide emissions were consistent with the measurements available, and greater than those from other intensive crops. Nitrous oxide emissions were predicted to vary considerably between regions, and were higher on irrigated soils and increased when trash was retained. Also, as expected, emissions were related to N fertiliser applications. Adoption of recent recommendations for reducing N fertiliser use was, in an example, predicted to reduce emissions by 40%. Further reductions in N applications and emissions, which may occur if emission trading schemes are adopted and fertiliser prices increase, were shown to reduce both emissions and profitability of sugarcane production. However, the economic value of reduced emissions is likely to be considerably less than that of the lost production. Experimental confirmation of these conclusions would be valuable.

Introduction

Concentrations of nitrous oxide, which is a potent greenhouse gas, have increased significantly over the past century as a result of anthropogenic alterations to the global nitrogen cycle (Crutzen et al., 2008; Schlesinger, 2009). Significant nitrous oxide emissions result from application of nitrogen (N) fertiliser to crops (Bouwman et al., 2002), and these emissions reduce the greenhouse gas benefits of biofuels (Crutzen et al., 2008). Hence, understanding nitrous oxide emissions from sugarcane production systems is an essential prerequisite for maximising the benefits of biofuels production, as well as minimising overall environmental impacts.

There are few measurements of nitrous oxide emissions from sugarcane and most have been conducted in Australia (Weier et al., 1996, 1998; Weier, 1999; Denmead et al., 2008; Wang et al., 2008; Allen et al., 2008; Macdonald et al., 2009). Emissions have been higher than expected compared with other cropping systems in Australia (Galbally et al., 2005). To reduce greenhouse gas emissions, it will be valuable to gain additional information on nitrous oxide emissions from
sugarcane systems and, if as high as currently indicated, identify management practices to reduce them.

Simulation models are increasingly being employed in addition to experiments to gain information on nitrous oxide emissions from cropping systems (e.g. Del Grosso et al., 2009). APSIM is a farming systems simulator (Keating et al., 2003) with a well developed capacity to simulate N dynamics in sugarcane systems (Thorburn et al., 2005). Recently, the denitrification processes in APSIM have been tested and the capability added for partitioning denitrified N into the different gasses produced by the process, nitrous oxide and dinitrogen (Thorburn et al., 2010a). Thus, APSIM is now a useful tool for exploring potential nitrous oxide emissions from sugarcane production systems in areas and/or for issues where measurements are unavailable.

In this paper, we use APSIM to investigate nitrous oxide emissions from a range of conditions found in sugarcane production in Australia. The simulations support the high nitrous oxide emissions previously measured, and suggest emissions are possibly greater in other sugarcane growing regions in Australia. We also explore some options for reducing nitrous oxide emissions and the impact they may have on sugarcane farming profitability.

**Methodology**

Contrasting sugarcane production systems were analysed using long term (40–60 years) simulations to investigate how nitrous oxide emissions varied (full details are given by Thorburn et al., 2010a). The systems were based on soils, climate and crop management information from previous studies of sugarcane production in four regions. These spanned a wide range of environments, including the super-humid tropics (Tully; ~17.9S, 145.9E), dry tropics (Burdekin River Irrigation Area; ~19.8S, 145.9E), humid tropics (Mackay, two soils; ~21.2S, 149.0E) and dry sub-tropics (Maryborough; ~25.5S, 152.7E).

Nitrous oxide emissions have previously been measured in the Mackay region, at Eton (Weier et al., 1998) and Te Kowai (Denmead et al., 2008; Macdonald et al., 2009). Hence, this study provided the first insights into potential nitrous oxide emissions in the other regions.

A range of management practices and soils were represented in the simulations. In Australia, there is a wide range of potential planting times, both within and between regions and this variation is represented in the systems simulated. The planting time influences the length of fallow before planting, and a range of fallow lengths is represented in the systems simulated. Irrigation management varied, with sugarcane fully irrigated in the Burdekin simulations, grown under supplementary irrigation in Maryborough simulations and not irrigated in the other systems. Simulations for the two soils in Mackay each had two different trash managements (retention and removal).

The amount of N applied in the simulations reflected common practice in the regions, ranging from over 200 kg/ha (averaged across all crops and fallows) in the Burdekin region to less than 130 kg/ha in the Tully and Maryborough regions (Figure 1). Soils ranged from clays in the Burdekin and the Eton site in Mackay, to sandy-clay-loams at the Te Kowai site in Mackay. Average cane yields in the simulations ranged from 74 t/ha (averaged across all crops), at Maryborough, to 80–84 t/ha for the loamy soils at Tully and Mackay (Te Kowai), to 87–91 t/ha in the clay soils of Mackay (Eton) and the Burdekin.

For the Te Kowai site in Mackay, cane yield, nitrous oxide emissions and partial gross margin (PGM) to farmers of sugarcane production were also simulated for a wide range of N application rates (35–200 kg/ha), keeping all other management factors the same as in the previous simulations. The PGM was calculated from the income from sugarcane (assuming a sugar price of AUS400/t and CCS of 13.5) less the cost of N fertiliser. The N application rate corresponding to the highest PGM was identified over a range of fertiliser prices to explore the possible sensitivity of nitrous oxide emissions, which are a function of N rate, to N price.
Results and discussion

Extent of emissions

Simulated long-term nitrous oxide emissions varied from 4–6 kg N/ha at the rainfed sites (Mackay and Tully) to 5–11 kg N/ha for the irrigated sites (Burdekin and Maryborough). The simulated emissions are consistent with previous measurements of emissions from rainfed sugarcane (Denmead et al., 2008; Allen et al., 2008; Wang et al., 2008; Macdonald et al., 2009). In particular, at Te Kowai near Mackay, nitrous oxide emissions of 4.1–4.7 kg N/ha were measured from a crop in 2006–07 (Denmead et al., 2008) and over the first 60 days of a crop in 2007–08 (Macdonald et al., 2009), similar to average long-term simulated values of 3.2–4.2 kg N/ha. Our simulations suggest these results are representative of longer time frames.

Nitrous oxide emissions were equivalent to 2–5% of N fertiliser applied (Figure 1) in the simulations. These relative emissions were consistent with the processes known to drive nitrous oxide emissions. At the Mackay sites, for example, emissions were higher from the clay soil at Eton than the more loamy soil at Te Kowai. Also, retaining trash on these soils increased simulated denitrification and nitrous oxide emissions, as expected from experimental results (Weier et al., 1998). Emissions were simulated to be high at the Burdekin site, reflecting the heavy clay nature of the soil combined with the high number (16) of irrigations in the simulation.

Our results (Figure 1) support the conclusions from several previous experiments (Denmead et al., 2008; Allen et al., 2008; Wang et al., 2008; Macdonald et al., 2009) that nitrous oxide emissions from Australian sugarcane crops are substantially greater than expected for the level of N fertiliser use and experience in other crops (Galbally et al., 2005), and suggest the cause is the relatively warm and moist climate and the availability of carbon in the soils.

Additionally, we provide the first estimates of emissions for fully irrigated production in Australia’s dry tropics (Burdekin), partly irrigated production in the sub-tropics (Maryborough) and rainfed production in the wet tropics (Tully). It will be valuable to experimentally confirm our predictions for these regions. However, we suggest that nitrous oxide total emissions in Australian sugarcane production may generally be equivalent to 3 to 5% of N fertiliser. While very high
emissions (~20% N fertiliser) have been measured from sugarcane growing on organic soils with shallow water tables (Denmead et al., 2008; Wang et al., 2008), these areas are relatively small in Australia and are unlikely to represent the general situation.

Global warming potential of nitrous oxide emissions from Australian sugarcane production has been estimated at 1.3 Mt CO$_2$-e/year (Weier, 1998), compared to total nitrous oxide emissions from agricultural soils in Australia of 15 Mt CO$_2$-e/y (NGGI, 2007). Our predicted nitrous oxide emissions are equivalent to 2.2–3.8 Mt CO$_2$–e/year for the amount of N traditionally applied to sugarcane in Australia (~80 Mt/year; Fertiliser Industry Federation of Australia, pers. comm.). Thus, we suggest that global warming potential of sugarcane in Australia is substantially greater than the previous estimate.

Applying our results to global sugarcane production for the area occupied by the crop (FAO, 2007) and average N application rates (Roy et al., 2006) suggests the global warming potential of nitrous oxide emitted from all sugarcane production may be equivalent to 60–100 Mt CO$_2$–e/year. This is 2–3% of the global warming potential previously attributed to nitrous oxide emissions from all fertilised croplands (Stehfest and Bouwman, 2006). This result, together with the fact that nitrous oxide emissions account for more than half the greenhouse gasses emitted during sugarcane production (Thorburn et al., 2009), suggests that reducing nitrous oxide from sugarcane is likely to be a higher priority than may have been previously thought for increasing the sustainability of sugarcane production both in Australia and globally.

Reducing emissions

As expected (Bouwman et al., 2002), nitrous oxide emissions increase with increasing N fertiliser application (Figure 2a). Thus, emissions can be reduced by reducing N applications. This may come about in two ways:

Firstly, improved N recommendations have shown there is considerable scope for reducing N rates in Australian sugarcane production without significantly reducing productivity (Schroeder et al., 2006; Thorburn et al., 2010b). Thus, at Te Kowai for example (Figure 2a), reducing N application from 170 kg/ha (the recent average in that region) to 120 kg/ha would reduce nitrous oxide-N emissions by ~40%. This reduction in emissions would not be associated with a loss of income as yields are likely to be maintained at these N application rates (Thorburn et al., 2010b).

Secondly, nitrogen applications may also be reduced if the price of N fertiliser increases. Price increases are likely if emissions trading schemes are introduced, because the cost of energy used in the manufacture and distribution of fertiliser will rise, and the possibility of an emissions levy on fertiliser.

As N fertiliser prices increase, maximum profitability occurs at lower N application rates (Figure 2b). So farmers may respond to price increases by reducing N applications, which would result in lower nitrous oxide emissions. However, with increased N price, not only is the N rate at which maximum profitability reduced, the maximum profit itself also decreases.

Thus, higher N prices could result in both lower nitrous oxide emissions and lower farm profitability if farmers respond by reducing N applications. In the simulations for Te Kowai, the trade off between nitrous oxide emissions and farm profitability can be illustrated for varying N prices by taking the N rate at which maximum PGM occurs (i.e. the dots on the curves in Figure 2b) and calculating the corresponding nitrous oxide emissions and PGM values over a range of N prices (Figure 3).

In this example, nitrous oxide emissions decrease by ~0.46 kg N$_2$O-N/ha for each unit (i.e. AU$1) increase in N price. If the price of carbon is AU$20/t CO$_2$-e the value of the reduced nitrous oxide emissions is ~AU$4.25. The corresponding decrease in PGM is ~AU$98 per unit increase in N price, or more than 20 times the value of nitrous oxide emissions.
The economic impact of increased N prices will be even greater if price increases are such that they drive N applications low enough so that cane yields and sucrose concentrations are reduced. In this situation, the reduced cane and sugar supply would potentially reduce mill profitability. This analysis illustrates the point that decreases in N fertiliser rate below recommended rates as a response to higher N prices could have substantial negative net economic effects.

The nitrous oxide emissions are enhanced by high concentrations of nitrate and carbon in the soils and anaerobic soil conditions. Thus, as well as reducing N fertiliser applications, other management practices affect nitrous oxide emissions. In our simulations, as expected, the highest relative emissions occurred in the two irrigated production systems, Burdekin and Maryborough (Figure 1). In irrigated production systems, minimising water logging following irrigation will help reduce nitrous oxide emissions. Also, as expected, retaining crop trash also increased emissions (Figure 1).

Given the advantages of this widely-adopted practice in Australian sugarcane production (Weier et al. 1998; Robertson and Thorburn, 2007), other methods to reduce emissions will need to be employed. Practices such as splitting N fertiliser applications may help (Weier 1999; Allen et al., 2008), as might slow release fertilisers or nitrification inhibitors (Wang et al., 2008), although the benefits of these practices have not been consistent.
Conclusions

Our study supports the proposition that nitrous oxide emissions from Australian sugarcane production are considerably greater than expected compared with measurements in other intensive crops, and so reducing emissions will be important for increasing sustainability of the industry. Adoption of contemporary recommendations for reducing N fertiliser use is a likely pathway to significantly reducing emissions.

Further reductions in N applications, which may occur if emission trading schemes are adopted and fertiliser prices increase, may not only reduce emissions, but profitability of sugarcane production. The economic value of lost production is likely to be much greater than the value of reduced greenhouse gas emissions. Experimental confirmation of these conclusions would be valuable. Simulating the relative efficacy of these different management practices may guide experimentation in that area. APSIM’s ability to represent such management options in detail (Keating et al., 2003; Thorburn et al., 2005) will make it a useful tool for these investigations.

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REFERENCES


PERSPECTIVES ET CONSÉQUENCES POTENTIELLES DES RÉDUCTIONS D'ÉMISSIONS DE PROTOXYDE D'AZOTE EN CULTURE DE CANNE À SUCRE

Por

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MOTS-CLÉS: APSIM, Biocarburants, Émissions de Gaz à Effet de Serre, Émissions de Protoxyde D'azote, Engrais d'Azote, Canne à Sucre.

Résumé

L'UTILISATION de l'engrais azoté est une cause majeure de l'accroissement des concentrations atmosphériques en protoxyde d'azote, un gaz à effet de serre potentiel. Pour réduire les émissions de gaz à effet de serre provenant de la production de canne à sucre, et augmenter ainsi l’intérêt de cette plante comme biocarburant durable, il serait important d'avoir une meilleure connaissance des émissions de protoxyde d'azote et des façons de les réduire. Cependant, peu de mesures de pertes en protoxyde d'azote ont été relatées jusqu'ici. Ainsi, notre connaissance sur les émissions de protoxyde d'azote des systèmes de production de canne à sucre, et leur variabilité selon les conditions environnementales et les pratiques culturales, est limitée. Nous avons comparé des mesures d’émissons de protoxyde d'azote aux prévisions du modèle de croissance APSIM. Nous avons ainsi simulé des émissions de protoxyde d'azote de parcelles sur une gamme d’environnements et de pratiques culturales en Australie. Les prévisions des émissions de protoxyde d'azote furent conformes aux mesures disponibles, et supérieures à celles d'autres cultures. Les émissions de protoxyde d'azote ont été simulées pour des régions très variées, et furent plus élevées sur sols irrigués et accrues quand les résidus de récolte étaient restitués. En outre, comme prévu, les émissions furent liées aux applications d'engrais azoté. L'adoption des recommandations récentes pour réduire l'utilisation d'engrais azoté, dans un exemple, réduisit les émissions de 40%. D'autres réductions des applications d'azote et des émissions, qui peuvent se produire si les plans de taxation des émissions sont adoptés et si les prix d'engrais augmentent, ont montré une réduction à la fois des émissions et de la rentabilité de la production de canne à sucre. Cependant, la valeur économique des émissions réduites est vraisemblablement plus faible que celle due à la réduction de production. Une confirmation expérimentale de ces conclusions serait très utile.
OPORTUNIDADES Y CONSECUENCIAS POTENCIALES DE LA REDUCCIÓN DE LAS EMISIONES DE OXIDO NITROSO EN CULTIVO DE CAÑA DE AZÚCAR

Par

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PALABRAS CLAVES: APSIM, Los Biocarburantes, Gases de Efecto Invernadero, Emisiones de Óxido Nitroso, Fertilizantes de Nitrógeno, Caña de Azúcar.

Resumen
El uso de los fertilizantes nitrogenados es la principal causa de incremento de las concentraciones atmosféricas de óxido nitroso, un potente gas de efecto invernadero. Para reducir las emisiones de gas de efecto invernadero en la producción de caña de azúcar, y para incrementar la atractividad del cultivo como un biocombustible sostenible, será importante tener un mejor entendimiento de las emisiones de óxido nitroso y de cómo pueden reducirse. Sin embargo, pocas mediciones de pérdidas de óxido nitroso han sido reportadas hasta el momento. Por lo tanto, nuestro conocimiento es limitado sobre las emisiones de óxido nitroso desde los sistemas de producción de caña de azúcar, y de cómo podrían variar en respuesta a las diferentes condiciones ambientales y de manejo. Hemos comparado mediciones de emisiones de óxido nitroso con predicciones hechas a partir del modelo de sistemas de cultivo APSIM. Luego, hemos simulado las emisiones de óxido nitroso del cultivo completo sobre un rango de ambientes y prácticas de manejo en Australia. Las predicciones de las emisiones de óxido nitroso fueron consistentes con las mediciones disponibles, y mayores que aquellas provenientes de otros cultivos. Se predijo que las emisiones de óxido nitroso variarían considerablemente entre regiones, y fueron más altas en los suelos irrigados e incrementadas cuando se mantuvo el residuo de la cosecha. También, como se esperaba, las emisiones estuvieron relacionadas a las aplicaciones de fertilizantes nitrogenados. En un ejemplo, la adopción de las recomendaciones recientes para la reducción del uso de fertilizantes nitrogenados, predijo la reducción de las emisiones en un 40%. Además, las reducciones en las aplicaciones de nitrógeno y en las emisiones, que pueden ocurrir si se adoptan los planes propuestos en los protocolos, y el precio de los fertilizantes aumenta, demostramos que se reducen tanto las emisiones como la rentabilidad de la producción de caña de azúcar. Sin embargo, el valor económico de las emisiones reducidas es probablemente considerablemente menor que el de las pérdidas de producción. La confirmación experimental de esas conclusiones debería ser evaluada.
EVALUATING AN ECOLOGICALLY-BASED SYSTEM FOR SUSTAINABLE MANAGEMENT OF NITROGEN FERTILISER

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KEYWORDS: Nitrogen Surplus, Sugarcane Nitrogen Concentration, Farm Profitability, Best Management Practice, Environmental Impact.

Abstract
SUSTAINABLY managing N fertiliser is an increasing challenge for sugarcane production, as losses of N impact the health of ecosystems and contribute to climate change (through emissions of the greenhouse gas nitrous oxide). The N Replacement (NR) system is a new, ecologically-based concept for N management in sugarcane designed to meet this challenge. The NR system aligns N applications with actual cane production, rather than potential production, by relying on soil N reserves to buffer differences in crop N needs and N fertiliser supply in individual crops. We evaluated the NR system in 11 on-farm experiments in Australia, conducted over a wide range of environments for up to five years. Average yields in the NR treatment were similar to those achieved with the farmers’ conventional N management that had average N applications 66 kg/ha greater than in the NR treatments. Yields increased relative to the farmers’ conventional N management through time, from ~5 t/ha lower in the first crops of the experiments to 2.6 (standard error = 1.2) t/ha higher in the fourth, suggesting a physiological response in the crops to the variable N applications in the NR system. The crop N surplus, an estimate of N potentially lost to the environment, was 55% lower in the NR treatment compared with conventional N management. This reduction in N surplus was not as great as had been anticipated, as N concentrations and N uptake in cane for most crops in all treatments were lower than those previously reported. The results show that the ecologically-based N Replacement system may deliver superior environmental outcomes without significantly reducing production. The results also show that predicting yield of the coming crop, a common basis for N management, is not necessary in sugarcane N management, provided N applications and production are matched in the longer term.

Introduction
Controlling N losses from cropping systems is important because of the impacts of N on human health and ecosystems (predominantly as NO₃) and its role in contributing to climate change (through N₂O emissions). These are challenging issues for sugarcane production, which has generally high use of N fertiliser (Roy et al., 2006) and is increasingly used for biofuel production (Macedo et al., 2008). It is unlikely that traditional N fertiliser recommendations for sugarcane will meet these challenges. Potential crop yields are a feature of many recommendation systems (e.g. Legendre, 2001; Schroeder et al., 2006) and so result in over-application of N in the common situation where actual production is less than potential (Meyer et al., 2007).

Sugarcane is a deep rooting semi-perennial crop (i.e. it is allowed to ratoon after harvesting) grown in subtropical and tropical areas where soil N cycling is often rapid. This rapid N cycling allows large amounts of N to be immobilised and subsequently mineralised over the long term (Ng Kee Kwong et al., 1986; Meier et al., 2006) where it can be efficiently retrieved by the deep root system (Smith et al., 2005). Therefore sugarcane may be well suited to a more ecologically-based
approach to N management (Drinkwater and Snapp, 2007), where N fertiliser applications are geared to maintaining soil N stores so they can provide the crop’s N needs, rather than more directly ‘feeding’ the crop.

Such an ecologically based N management system, known as N Replacement (NR), was proposed for sugarcane by Thorburn et al. (2004). They linked N applications to crop N off-take in the previous crop. The assumption was that, if the yield of the coming crop was larger than that of the previous crop, additional N requirements would be supplied from soil N stores. Conversely, these N stores would be ‘topped up’ when a small crop followed a large one. They suggested a potential saving in N fertiliser up to 40% compared with common N fertiliser applications in Australia, and consequently the N surplus (an estimate of the N potentially lost to the environment) may be reduced by 90%.

In this paper we report on 11 field experiments established to test this concept in the diverse soils and climates of the Australian sugarcane industry. As well as evaluating whether the NR system can maintain sugarcane productivity with lower N fertiliser inputs and environmental impacts, we also discuss the implications of the results for general sugarcane N management strategies.

**Methods**

Experiments were established on commercial farms in 2003 or 2004 located from the wet tropics around Cairns (~16°S – Mossman, Mulgrave and Innisfail, Table 1), to the dry tropics near Townsville (~19°S – Burdekin), and the sub-tropics (~25°S to 28°S – Bundaberg, Maryborough and Condong). Crops at sites BK-1, BK-2, BU-1 and MB-1 were irrigated and the others rainfed. The irrigated crops, except at BU-1, were burnt at harvest. Others were harvested unburnt with all trash retained on the soil surface. The NR system was compared with the farmers’ conventional N fertiliser management (NF).

The amount of N fertiliser (kg/ha) applied in the NR approach was targeted to be 1 kg N/t cane harvested in the previous crop where trash was retained and 1.3 kg N/t cane where the crop was burnt (Thorburn et al., 2004). This is less than general application rates to sugarcane (Roy et al., 2006) and, particularly where trash is retained, less than current recommendations in Australia (Schroeder et al., 2006). In five of the experiments, a lower N rate treatment (NL) was also included to examine the time taken for productivity to decline as a consequence of low N applications. The lower rate was approximately equivalent to that which would occur with the NR scheme following a very poor crop.

**Table 1**—Details of the experimental sites and the average annual N applied in different treatments (NL-N Low; NR-N Replacement; NF-N Farm).

<table>
<thead>
<tr>
<th>Site code</th>
<th>Region</th>
<th>Texture</th>
<th>Total C (%)&lt;sup&gt;a&lt;/sup&gt; (0–0.6 m)</th>
<th>Total C (%)&lt;sup&gt;a&lt;/sup&gt; (0–0.3 m)</th>
<th>Reps</th>
<th>Average N applied (kg/ha)</th>
<th>NL</th>
<th>NR</th>
<th>NF</th>
</tr>
</thead>
<tbody>
<tr>
<td>BK-1</td>
<td>Burdekin</td>
<td>Sandy clay loam</td>
<td>0.77</td>
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<td>159</td>
<td>318</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BK-2</td>
<td>Burdekin</td>
<td>Sandy clay loam</td>
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<td>2 na</td>
<td>218</td>
<td>326</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BU-1</td>
<td>Bundaberg</td>
<td>Sandy loam to sandy light clay</td>
<td>0.75</td>
<td>3 35</td>
<td>95</td>
<td>140</td>
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<td></td>
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<tr>
<td>CD-1</td>
<td>Condong</td>
<td>Light clay</td>
<td>2.03</td>
<td>2 67</td>
<td>143</td>
<td>149</td>
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<td></td>
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<tr>
<td>IN-1</td>
<td>Innisfail</td>
<td>Sandy clay</td>
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<td>3 68</td>
<td>88</td>
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<td></td>
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<tr>
<td>IN-3</td>
<td>Innisfail</td>
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<td>1 na</td>
<td>110</td>
<td>144</td>
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<td>Maryborough</td>
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<td>1.21</td>
<td>1 63</td>
<td>128</td>
<td>160</td>
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<td></td>
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<tr>
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<td>1.12</td>
<td>3 55</td>
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<td>ML-1</td>
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<td>Sandy clay</td>
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<td>1 na</td>
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<tr>
<td>MS-1</td>
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<td>93</td>
<td>174</td>
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<td></td>
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</tr>
</tbody>
</table>

<sup>a</sup> Soil C concentration determined by combustion with a LECO CNS analyser.

<sup>b</sup> The NL treatment was not established at every site.
Generally the sites had been managed using the farmers’ normal practice prior to the experiments. The exception was BU-1, where the experiment was established in the first ratoon crop of a pre-existing N rate experiment (Thorburn et al., 2003).

In this experiment, the NR treatment was applied to plots that had received no N fertiliser in the preceding plant crop (yielding 83 t/ha). Also, unlike the other sites, the NL treatment had received a lower-than-recommended rate of fertiliser since 1996.

A participatory approach was taken to the experimental designs at each farm, so these were decided jointly with collaborating farmer groups. Seven experiments were established as randomised designs with treatments replicated, while four were non-replicated demonstration experiments (Table 1).

All cultural practices and the timing of these operations were determined by the collaborating farmers. This approach was taken to ensure crop production reflected that achieved on commercial farms, and not higher yields often achieved in more carefully managed experiments.

Plots were generally large enough to allow harvested cane yield and sugar content to be determined from commercial harvesting and milling operations.

Crop biomass and N concentrations were determined prior to harvest to allow calculation of crop N dynamics. Where treatments were replicated and run over multiple harvests, the results were subject to analysis of variance using a strip-plot design.

The surplus of N was calculated for each treatment as the difference between N applied and that lost through crop harvest and, where applicable, trash burning.

The amount of N in the crop and trash was determined from mass and N concentration in the harvested cane and trash. N surpluses are calculated from the sum of all the harvest years and reported as an annual average.

**Results**

Yields were generally similar in the NR and NF treatments (Figure 1). However, there was a trend for yields in the NR treatments to be less than those in the NF treatment in the first year of the experiment, but increase relatively in each successive year.

In the five experiments in which at least four crops were grown, the yields in the NR treatment were 2.0 (standard error = 0.6) and 2.6 (1.2) t/ha greater than those in the NF treatment in the 3rd and 4th crops, respectively.

The relative increase in yield in the NR treatment was most marked at the BU-1 site. At this site, the NR treatment was established on a plot in which soil N reserves had been run-down.

So the relationship between yield-response to increasing N applications in the first two crops was not surprising.

More surprising was the higher average yields in the NR treatment for the third and fourth crops at this site.

There were no significant yield differences in the replicated experiments, despite the fact that N applications were on average 66 kg/ha lower using the NR treatment than the NF.

Yields in the NL treatment averaged 11 t/ha lower than those in the NF treatment receiving higher N (Figure 1).

The biggest difference was at the BU-1 site where the NL treatment had been imposed for 8 years prior to this experiment, and so soil N is likely to have run down.

Excluding this site, the average yield reduction was 6.2 t/ha, trending from 5 t/ha in the first crop after the treatments were imposed, to 8 t/ha in the third.
Cane N concentrations, a major component of crop off-take of N, were variable between sites (Figure 2), e.g. ranging from ~0.3% in some crops at sites BK-1 and BK-2 to <0.1% at MB-2. Cane N concentrations also varied between years, e.g. 0.2% in 2005 and 0.1% in 2006 at site IN-3. They also tended to be lower in the NL treatment, presumably responding to the markedly lower N applications in this treatment (Table 1). There was little difference in N concentrations in cane from the NR and NF treatments in most experiments, exceptions being sites BK-1 and ML-1 where there was a trend in three of the four years for cane N concentrations to be lower in the NR treatment.

The amount of surplus N generally increased with increasing N applications, averaging 5 kg/ha in the NL treatment, 63 kg/ha in the NR treatment and 141 kg/ha in the NF treatment, although the values were highly variable across sites (Figure 3).

Despite the variability, N surplus in the NR treatment was less than those in the NF treatments at all sites, except CD-1 where there was little difference between the N fertiliser applied in these two treatments. The average reduction in N surplus (55%) was less than that predicted by Thorburn et al. (2004), the reason being that the N concentrations measured in most crops (Figure 2) were lower than the 0.3% assumed by Thorburn et al. (2004) based on previous measurements (Wood et al., 1996).
Fig. 2—Concentrations of N in cane of sugarcane crops in the experiments. Treatment designations are the same as in Figure 1. Note: Samples at sites IN-1 and MS-4 were not obtained in all crops.

Fig. 3—The N surplus (i.e. the difference between N applied and that lost in harvested cane and, at some sites, burnt trash) averaged over all sugarcane crops harvested from the experiments. Treatment designations are the same as in Figure 1. Note: There are no results for site IN-1 in 2006 due to cyclone damage.

Discussion
These results suggest the NR system has promise for meeting the productivity needs of N fertiliser management in sugarcane while reducing potential environmental losses of N for the range of conditions represented in the 11 experiments of this study. Yields were similar to those with
higher and more conventional (Schroeder et al., 2006; Roy et al., 2006) applications of N (Figure 1), especially in the second and subsequent crops after the treatments were imposed. N surpluses (Figure 3), and so potential environmental impacts, were also reduced by ~55% compared with conventional N management.

The improved outcome of the NR system over the farmers’ conventional management was potentially due to a number of factors.

Firstly, yields in all treatments were generally lower than potential yield benchmarks in the regions which drive current thinking on farmers’ N management. For example, potential yields in the regions in which the experiments were located were generally 120 t/ha, and 180 t/ha in the Burdekin region (Schroeder et al., 2006). These yields were only reached or exceeded in 7 of the 37 crops grown in the experiments. And in those crops, e.g., CD-1 in 2005 or MB-2 in 2007 (Figure 1), there was no evidence that the lower N applied in the NR treatment was limiting yields.

Secondly, cane N concentrations (Figure 2) were generally lower than expected from previous studies (Wood et al., 1996) across all treatments and sites, meaning that the crops’ N needs were lower than anticipated.

Thirdly, this improved outcome suggests that the philosophy of drawing on dynamic N cycling in sugarcane soils (Ng Kee Kwong et al., 1986; Meier et al., 2006) to buffer some of the short term differences between crop N needs and N supply from fertiliser is applicable in sugarcane production. This final point suggests that the concept of applying N to ‘feed’ potential yields may not be necessary for sustainable sugarcane production, particularly when actual yields do not realise their potential. A more ecologically-based approach to N management, where fertiliser applications are geared towards maintaining soil N stores, as advocated by Drinkwater and Snapp (2007), may be applicable to sugarcane.

The results from these experiments allow us to explore the degree to which N fertiliser applications need to match ‘expected yields’, and hence the degree of buffering soil N reserves provided to these sugarcane crops. Since, in the NR system, N applied is based on yield of the previous crop, N applications will only be equal to the ‘needs’ of the coming crop if yields are constant over a number of crops. Where yields increase through time, N applications will be lower than those needs, and so crops must draw on soil supplies, as would be the case when yields are higher than expected.

This situation happened in the NR treatment at site MB-2. Yields of the 2006 and 2007 crops were 25 and 30% higher than the previous crop (Figure 1), resulting in actual N applications of ~0.8 kg N/t cane relative to the achieved yield. Yet, applying extra N fertiliser (average of 47 kg/ha) in the NF treatment in these years did not significantly increase yield, particularly in the 2007 crop. Additionally, the NR treatment at the BU-1 site was established following a crop that received no N, yet after two crops yields had recovered to averages greater than those of the NF treatment that had received 45 kg/ha extra N fertiliser. These results show that, from crop to crop, actual yields can be considerably higher than expected yields without N supply being limiting.

As hypothesised by Thorburn et al. (2004) in conceiving the NR concept, the soil N cycling processes provided sufficient N for crop N needs in the N replacement system in the short term, and it is more important to match N applications to longer-term actual production.

There were some unexpected physiological responses in the crops of the experiment. Firstly, as discussed above, cane N concentrations (Figure 2) were generally lower than those previously measured in Australian sugarcane crops (Wood et al., 1996). These unexpectedly low cane N concentrations may be possibly due to the physiology of modern Australian varieties which, if so, indicates that there may be potential for further reductions in N fertiliser applications to sugarcane crops. Rather than seeking N rates for optimum yield, a more useful approach for determining the
potential reductions may be to ask the question; what is the minimum long-term N surplus required to maintain crop yields?

The NR treatment had an average N surplus of 63 kg/ha (Figure 3), or ~0.5 kg N/t cane, and this was sufficient to maintain productivity (Figure 1) compared with the higher N applications (Table 1). It was also sufficient to overcome a deliberate rundown of soil N reserves at the BU-1 site within one or two crops. The question now is whether productivity can be maintained at lower N surpluses?

The second physiological response was the trend for yields in the NR treatments to increase relative to those in the NF treatment over successive crops (Figure 1). This result suggests that the crops were ‘compensating’ for the lower, but variable, N application in this treatment. Sugarcane crops can respond to N through deeper root development (Smith et al., 2005), a possible explanation for the results in this experiment.

Such compensation, together with the lower than expected cane N concentrations observed in these crops suggest that there are further gains to be made in lowering N inputs to, and hence environmental impacts of, sugarcane production.

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ÉVALUATION D'UN SYSTÈME ECOLOGIQUE DE GESTION DURABLE DE LA FERTILISATION AZOTEE

Por

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MOTS-CLÉS: Excédent d'azote, Teneur en Azote de la Canne à Sucre, Rentabilité de l’exploitation, Meilleure Pratique de Gestion, Incidences sur l'Environnement.

Résumé
LA GESTION durable de la fertilisation azotée est un défi croissant de la production de canne à sucre, car les pertes en N affectent la santé des écosystèmes et contribuent au changement climatique (par des émissions de protoxyde d'azote, un gaz à effet de serre). Le système de remplacement de N (NR) est un concept nouveau, à base écologique, de gestion de N en canne à sucre, conçu pour relever ce défi. Le système de NR préconise des applications d'azote en accord avec la production réelle de canne, plutôt que la production potentielle, et tenant compte des réserves du sol en N pour tamponner les différences entre les besoins en N par la plante et les fournitures en azote par le sol. Nous avons évalué le système NR sur 11 essais menés sur exploitation en Australie, conduits sur un large éventail d'environnements pendant cinq années. Les rendements moyens dans le traitement NR furent similaires à ceux produits par la gestion conventionnelle de N des exploitants qui a nécessité des applications d'azote moyennes 66 kg/ha, bien plus grandes que celles des traitements NR. Comparés à la gestion conventionnelle, les rendements produits par le système NR a augmenté dans le temps, passant de ~5 t/ha dans les premières récoltes à + 2.6 t/ha dans le quatrième récolte, suggérant une réponse physiologique variable des plantes aux applications d'azote dans le système NR. L'excédent d'azote, potentiellement perdu vers l'environnement, était 55% plus faible dans le traitement NR qu'avec la gestion conventionnelle de N. Cette réduction d'excédent de N ne fut pas aussi grande que prévue, car les concentrations en N de la canne et la mobilisation de N par la plante dans la plupart des traitements furent inférieures à celles précédemment rapportées. Les résultats montrent que le système écologique de remplacement de N mobilisé peut améliorer l’impact environnemental sans réduire de manière significative la production. Les résultats montrent également que le rendement prévu, un critère commun du calcul de l’azote à fournir, n’est pas nécessaire dans la gestion de N chez la canne à sucre, si les applications de N et la production sont raisonnées à plus long terme.
EVALUACIÓN DE UN SISTEMA BASADO ECOLOGICAMENTE EN EL MANEJO SUSTENTABLE DEL FERTILIZANTE NITROGENADO

Par

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PALABRAS CLAVE: Nitrógeno Excedente, Concentración Nitrógeno
Caña de Azúcar, Rentabilidad Finca (Campo),
Mejor Práctica de Manejo, Impacto Ambiental.

Resumen

El manejo sustentable de los fertilizantes nitrogenados es un desafío creciente para la producción de caña de azúcar, porque las pérdidas de N impactan la salud de los ecosistemas y contribuyen al cambio climático (a través de las emisiones de óxido nitroso como gas de efecto invernadero). El sistema de Reemplazo de N (NR) es un concepto nuevo, ecológicamente basado en el manejo del N en caña de azúcar diseñado para responder a este desafío. El sistema NR relaciona las aplicaciones de N con la producción actual de caña, más que con la producción potencial, teniendo en cuenta las reservas de N del suelo para atenuar las diferencias entre las necesidades de N del cultivo y la adición de fertilizante nitrogenado en cada cultivo. Evaluamos el sistema NR en 11 sitios experimentales en Australia, sobre un amplio rango de ambientes por un período de hasta cinco años. Los rendimientos promedios en los tratamientos NR fueron similares a aquellos registros de los agricultores con manejo convencional de N, que hicieron aplicaciones promedio de 66 kg/ha de N, más altas que en los tratamientos NR. Hubo incrementos de rendimientos relativos de los agricultores de manejo convencional de N a través del tiempo, desde menos de 5 t/ha en el primer cultivo (año) de los experimentos, hasta 2.6 t/ha en el cuarto, sugiriendo una respuesta fisiológica en los cultivos a la variable aplicación de N en el sistema NR. El N excedente en el cultivo, un estimado de N potencialmente perdido hacia el ambiente, fue 55% más bajo en el tratamiento NR comparado con el manejo convencional de N. Esta reducción en el excedente de N no fue tan grande como había sido anticipada, porque las concentraciones de N y la asimilación de N en la caña para la mayoría de los cultivos en todos los tratamientos fueron menores que aquellas previamente reportadas. Los resultados mostraron que sistema de reemplazo de N basado ecológicamente puede extraer (aprovechar) más la entrega ambiental sin reducción significativa de la producción. Los resultados mostraron también que la predicción de rendimiento del cultivo siguiente, una base común para el manejo del N, no es necesaria en caña de azúcar, siempre que las aplicaciones de N y la producción estén igualadas en el largo plazo.
CHANGES IN SOIL ORGANIC CARBON STOCKS RESULTING FROM SUGARCANE CROPPING IN THE HUMID TROPICAL CLIMATE OF MAURITIUS: RESULTS FROM $^{13}$C NATURAL ABUNDANCE

By

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KEY WORDS: Soil Organic Carbon, Delta $^{13}$C, Sustainable Sugarcane Production.

Abstract

A DECLINE in productive capacity of soils as a consequence of long-term sugarcane monoculture, combined with an intensification of the production system, has become a major issue in several sugarcane producing countries. Maintenance of adequate levels of soil organic carbon (SOC) is crucial for the biological, chemical and physical functioning of soils. This study was conducted to determine the impact of long-term sugarcane monoculture on SOC stocks and to quantify the loss of native SOC and accretion of sugarcane-derived C following the adoption of new management practices namely derocking/landgrading and mechanised harvesting. Five study sites representing the five major soil groups under sugarcane in Mauritius were studied and a classical ‘paired-plot’ design was adopted where two sites with similar starting conditions were developed in different ways over time, with one representing the reference soil (virgin land with predominantly C$_3$ type vegetation) and the other representing the following cropping treatments: (i) fields continuously cultivated with sugarcane for more than 25 or 50 years without derocking or land grading, (ii) fields under long-term sugarcane but having undergone derocking and land grading for mechanised harvesting in the last 3 years. Soil samples were taken to a depth of 50 cm and analysed for total organic C, $^{13}$C abundance, bulk density and stone content. Long-term sugarcane cultivation reduced SOC stocks in the surface 0–15 cm layer compared to uncultivated virgin soil but increased subsoil organic C indicating a redistribution of SOC in the deeper layers of the soil profile. Changes in total C stock in the 0–50 cm profile, following 50 years of cane cropping were not significant ($P< 0.05$) compared to virgin land at any site. Data from $^{13}$C abundance measurements revealed that long-term sugarcane cultivation in fact resulted in a depletion of original SOC by 34 to 70%. However, this loss was fully compensated by C input from sugarcane residues at all sites studied, resulting in no net change in SOC stock. Moreover, adoption of mechanised cropping, which entails intensive derocking and land grading, did not have any detrimental effect on SOC stocks due to C inputs from crop residues.

Introduction

In recent years, there has been increasing evidence of a decline in productive capacity of soils as a consequence of long-term sugarcane (Saccharum officinarum L.) monoculture combined with intensification of the production system (Garside et al., 1997a; Meyer and van Antwerpen, 2001). Excessive tillage at time of planting, severe compaction resulting from mechanised cultural operations as well as practices that deplete organic matter have also been identified as major factors
contributing to the yield decline (Pankhurst et al., 2003). Collectively, these management practices result in degradation of the soil in chemical, physical and biological properties as evidenced by reduced levels of SOC, lower CEC and pH, high bulk density, less microbial biomass and a build-up of detrimental soil organisms (Garside et al., 1997b).

In Mauritius, analysis of the trend in productivity expressed as the average annual yield of sugar per hectare also showed a decline during the last 30 years in spite of the introduction of higher yielding cane varieties and the adoption of improved management practices.

While research examining the link between the observed declining productivity trend and soil degradation is lacking for the sugarcane industry in Mauritius, the management practices adopted are in many ways similar to those that are known to have contributed to yield decline elsewhere.

In this context sugarcane cropping in Mauritius is strongly monoculture-based and in order to facilitate mechanisation of cultural operations, land preparation involves deep tillage and derocking of the topsoil and subsoil followed by levelling of the soil surface through cut and fill method. As a result of this monoculture and soil disturbance, it is feared that the SOC levels may have declined.

Indeed as reviewed by Haynes and Hamilton (1999), most studies on the long-term effects of sugarcane production have reported a decline in SOC, the magnitude of this loss varying widely depending on soil type, period of cropping and management practices.

The determination of losses of original SOC from native vegetation and its replacement by C derived from sugarcane origin is thus of capital importance to understand the dynamics of organic carbon in soils of Mauritius.

The use of $^{13}$C technique was preferred as it enables the separation of organic C pools into that of old and new vegetation so long as the two types of vegetation have contrasting photosynthetic pathways (C$_3$ versus C$_4$) (Balesdent et al., 1987).

The cultivation of a C$_4$ crop such as sugarcane in a soil developed under C$_3$ natural vegetation can provide information on the turnover of the original organic matter as well as the contribution of the C$_4$–C to the SOM pool.

A study was therefore initiated to evaluate the impact of long-term sugarcane monoculture and of changed management practices on SOC stocks in Mauritius by means of natural $^{13}$C natural abundance measurements.

**Materials and methods**

**Study sites**

The study was carried out at five locations representing the five major soil types of Mauritius. The soils at the study sites fall into two main soil groups: the mature ferralitic soils also known as Ferralsols (FAO-ISRIC-IUSS, 2006) or Oxisols (Soil Survey Staff, 1999) derived from highly weathered basalt and the immature latosolic soils also known as Cambisols (FAO-ISRIC-IUSS, 2006) or Inceptisols (Soil Survey Staff, 1999) derived from moderately weathered basalt rock. The main characteristics of the soils are given in Table 1.

The cropping systems studied at each of the five sites were:

1. natural vegetation (treatment NV)
2. continuous sugarcane for > 50 years under conventional practice (treatment 50Y) and
3. continuous sugarcane for > 50 years under conventional practice followed by recent (three years) derocking and mechanisation (treatment 3M).

In addition, a fourth treatment consisting of 25 years sugarcane under conventional practice (treatment 25Y) was included at two sites (Riche Terre and Médine).
Table 1—Soil characteristics at experimental sites.

<table>
<thead>
<tr>
<th>Location</th>
<th>Climatic zone (Rainfall mm/yr)</th>
<th>Classification (FAO WRB, 2006)</th>
<th>Treatment</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
<th>C:N ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Riche Terre</td>
<td>Sub-humid 1000–1500</td>
<td>Ferralsol</td>
<td>NV</td>
<td>13.8±0.8</td>
<td>75.1±1.3</td>
<td>8–10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>50Y</td>
<td>19.8±1.8</td>
<td>66.4±2.6</td>
<td>10–11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3M</td>
<td>18.0±1.7</td>
<td>70.0±2.3</td>
<td>9–11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>25Y</td>
<td>21.1±1.2</td>
<td>63.1±2.1</td>
<td>9–10</td>
</tr>
<tr>
<td>Beau Champ</td>
<td>Humid 1500–3200</td>
<td>Ferralsol</td>
<td>NV</td>
<td>21.2±0.6</td>
<td>62.4±2.5</td>
<td>11–14</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>50Y</td>
<td>18.8±0.4</td>
<td>66.2±0.9</td>
<td>11–12</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3M</td>
<td>31.0±1.4</td>
<td>41.7±3.8</td>
<td>11–13</td>
</tr>
<tr>
<td>Mon Désert Alma</td>
<td>Super-humid 2500–3800</td>
<td>Ferralsol</td>
<td>NV</td>
<td>27.2±0.7</td>
<td>32.0±1.2</td>
<td>13–14</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>50Y</td>
<td>27.4±0.7</td>
<td>34.5±1.3</td>
<td>12–13</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3M</td>
<td>30.6±0.9</td>
<td>30.8±1.1</td>
<td>12–13</td>
</tr>
<tr>
<td>Médine</td>
<td>Sub-humid 750–1500</td>
<td>Cambisol</td>
<td>NV</td>
<td>17.8±0.6</td>
<td>62.9±2.0</td>
<td>9–10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>50Y</td>
<td>21.2±0.7</td>
<td>49.8±3.3</td>
<td>10–11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3M</td>
<td>21.4±0.9</td>
<td>58.6±2.8</td>
<td>10–12</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>25Y</td>
<td>19.7±0.9</td>
<td>59.1±2.7</td>
<td>9–11</td>
</tr>
<tr>
<td>Savannah</td>
<td>Super-humid 2000–3200</td>
<td>Cambisol</td>
<td>NV</td>
<td>29.2±1.6</td>
<td>27.8±2.2</td>
<td>11–12</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>50Y</td>
<td>25.8±0.5</td>
<td>47.1±1.7</td>
<td>9–11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3M</td>
<td>25.0±0.4</td>
<td>53.1±2.2</td>
<td>10–12</td>
</tr>
</tbody>
</table>

The natural vegetation plots consisted of native trees and shrubs (C₃ photosynthetic pathway) but could at times have included some exotic C₄ grasses and had never been tilled or cultivated with sugarcane.

The conventional practice for sugarcane consisted of tillage to a depth of 20–30 cm and replanting of sugarcane every seven to 10 years with N, P, K fertilisation at recommended rates, and manual harvesting with trash retention, though at times pre-harvest burning of some fields might have been practised.

Derocking of soils (treatment 3M) involved tillage to more than 50 cm depth, raking of surface and subsurface rocks and boulders which were then removed from the field, followed by the levelling of the soil through cut and fill.

The study plots at any site were located one to two kilometres apart and were thus subjected to the same climatic and drainage conditions.

**Soil sampling and analysis**

For each cropping treatment, there were three field replicates of one hectare each and within each field replicate there were four sampling plots of 50 m². At each sampling plot, two trenches 1.5 m long, 0.3 m wide and 0.5 m deep were dug, extending from the middle of one cane interrow across the row to the middle of the next interrow.

Soil samples were collected from the trenches in four different depth layers namely 0–5, 5–15, 15–30 and 30–50 cm. All samples were air dried and sieved to pass a 2 mm screen.

Total C and δ¹³C were determined on a Europa Model 2020 ANCA-SL continuous flow isotope ratio mass spectrometer with a triple collector (Europa Scientific, Crewe, UK) and expressed as per mil deviation from V-PDB standard (Peterson and Fry, 1987).

**Calculation of C derived from C₃ and C₄ vegetation**

Fraction of total soil organic C derived from sugarcane (f) was calculated using the following isotope mass balance equation (Balesdent and Mariotti, 1996):
where $\delta_{\text{sample}}$ is the average $\delta^{13}C$ value of the sample for a given depth layer from sugarcane soil, $\delta_{\text{reference}}$ is the average $\delta^{13}C$ value of the corresponding sample from natural vegetation (reference) soil and $\delta_{\text{sugarcane}}$ is the average $\delta^{13}C$ value of sugarcane crop residues ($-12.05 \%$). Total SOC stocks (t/ha) were calculated using the following equation:

$$\text{Total SOC stocks (t/ha)} = \%C \times Z \times B \times (100-S) \quad (\text{Equation 2})$$

where $\%C$ is the carbon content of sample (percent), $Z$ is the layer thickness (m), $B$ is the bulk density (t/m$^3$) and $S$ is the stone content of soil (percent). Soil C stocks were corrected to an equivalent mass basis according to Solomon et al. (2002).

**Statistical analysis**

Statistical analysis of the data was carried out using the linear model analysis of variance (ANOVA) procedure of SAS statistical package (Enterprise Guide 4, SAS International 2006). Post hoc comparisons among treatment means were done using the Tukey test at $P=0.05$.

**Results and discussion**

**Effect of long-term cane cultivation on total C stocks**

In the Ferralsols, SOC stocks in the 0–50 cm profile under native vegetation increased from 98.7 t C/ha at Riche Terre (subhumid zone) to 117.6 and 160.2 t C/ha respectively at Mon Desert Alma (superhumid zone) and Beau Champ (humid zone) (Figure 1).

Although the soil at Mon Desert Alma has developed under the superhumid zone, its lower SOC stock compared to Beau Champ could be attributed to its lower silt plus clay content (59% at Mon Desert Alma v/s 83% at Beau Champ).

In the Cambisols, SOC stocks of uncultivated soils were similar, Medine (101.4 t C/ha) and Savannah (103.0 t C/ha), in spite of differences in rainfall regime and could be attributed to the higher silt plus clay content at Medine (81%) compared to Savannah (57%). Although a positive correlation between silt plus clay content and native SOC levels has been widely reported (Feller and Beare, 1997; Barthes et al., 2008), such a relationship was not consistent over all the soil groups of Mauritius.

In order to assess changes in SOC stocks between cropping systems, the SOC data for individual depth layers sampled were summed over two depth ranges (0–15 cm representing the topsoil and 15–50 cm representing the subsoil. In the Ferralsols, long-term sugarcane cropping decreased SOC stocks in the surface 0–15 cm layer by 24 t C/ha compared to the uncultivated virgin soil (representing 31% of the initial C stock) at Beau Champ. Similarly, surface C stock at Mon Desert Alma and Riche Terre declined by 6.3 and 4.9 t C/ha although these losses were not significant at $P<0.05$.

Further, the decline in topsoil organic C was accompanied by an increase in subsoil organic C of 15.3, 20.8 and 10.5 t C/ha respectively at Beau Champ, Mon Desert Alma and Riche Terre. These observations concord with the findings of McGarry et al., (1996) and Skjemstad et al., (1999) who reported a decline in organic carbon content in surface horizons but an increase in subsurface horizons after different periods of sugarcane cultivation in Australia. An accumulation of SOC in deeper soil layers under sugarcane has been attributed to rhizodeposition and continual turnover of root material at lower depth as evidenced by a higher proportion of sugarcane-derived C in the subsoil compared to topsoil organic matter as reported by De Resende et al., (2006).

However, our data on measurements of $\delta^{13}C$ in the present study showed that the topsoil was more depleted in native organic C than the subsoil (Table 2) suggesting that repeated ploughing resulted in a greater loss of original SOC and hence lower SOC stock.
Fig—1. Soil organic carbon stocks (t C/ha) in 0-15 and 15-50 cm depths under different cropping systems at the five study sites. (NV: land under natural vegetation; 50Y: >50 years sugarcane conventional practice; 25Y: 25 years sugarcane conventional practice; 3M: >50 years sugarcane conventional practice with recent mechanisation). For a given site and soil depth, bars with the same lower case letter were not significantly different at P= 0.05; bars with the same upper case letter indicate that SOC for the 50 cm profile were not significantly different at P= 0.05.

It could also be due to a downward redistribution of organic matter-rich topsoil due to tillage and disk harrowing carried out at the time of replanting (Maslica et al., 1986; McGarry et al., 1996) or to a vertical migration of organomineral complexes (Basile-Doelsch et al., 2009). In the Cambisols (Medine and Savannah), changes in SOC stocks in topsoil and subsoil resulting from long-term cane cultivation were not significant (P< 0.05).
Table 2—Proportion of sugarcane-derived C and loss of native C in 0–15, 15–50 and 0–50 cm depth layers after 25 years, > 50 years of sugarcane monoculture and recent mechanisation. Within one site, values along the same column followed by the same lower case letter were not significantly different at P > 0.05. Within one site, values along the same row followed by the same upper case letter were not significantly different at P > 0.05. 50Y: >50 years sugarcane monoculture; 25Y: 25 years sugarcane monoculture; 3M: >50 years sugarcane monoculture with recent mechanisation.

In this study, long-term sugarcane production resulted in a decline in SOC in the top 15 cm layer but not in total SOC stock in the 0–50 cm profile at any of the sites studied. Most previous reports of a decline in SOC under sugarcane cultivation have been based on measurements of SOC changes in the surface 10–20 cm depth layer only (Cerri and Andreux, 1990; Blair, 2000; Dominy et al., 2002) or over a short period of cane cultivation (e.g. Hartemink, 1998). On the other hand, Skjemstad et al., (1999) showed that SOC stock in the 0–80 cm profile did not decline as a result of long-term sugarcane cultivation in Australia.

Loss of original native C and incorporation of sugarcane-derived C

Although total SOC stocks in the 50 cm profile did not decline after long-term sugarcane cultivation, there was a marked depletion of the native SOC at all the study sites (Figure 2). The amount of native C lost ranged from 35 to 70% of the native C stock in the corresponding virgin soils (Table 3) and represented between 26 and 84 t C/ha. The highest loss of 70% was measured at Medine and could only partly be attributed to a decrease in soil clay content from an initial 63% in the virgin soil to 50% after >50 years of cane cropping. Although it is generally reported that clay and silt contents play an important role in the protection of SOC against mineralisation (Bationo and Buerkert, 2001; Bationo et al., 2007), a consistent relationship between the proportion of C lost and the soil clay content was not observed for all sites in the present study. Instead, factors such as climatic variations, mainly temperature, and cultural practices such as the frequency and intensity of tillage operations could have influenced the loss of native SOC.

Most of the loss in native C occurred in the surface 15 cm of soil, indicating that repeated tillage of topsoil at planting resulted in enhanced mineralisation of native C stocks. The measured losses of native carbon in this study were generally similar to values reported earlier. Thus Cerri et
al. (1985) showed that 50% of the original C$_3$–C in a Brazilian Ferralsol was lost during 12 years after conversion of forest to sugarcane production. The loss of native SOC was fully compensated by C inputs from sugarcane at all sites studied (Figure 2). This is in contrast to the generally reported net loss of total SOC due to a slower accretion of crop–derived C than the loss of native C (e.g. Dominy et al., 2002; Solomon et al., 2002).

Fig. 2—Native and sugarcane-derived soil carbon stocks in the surface 50 cm of soil at five sites. (NV: land under natural vegetation; 50Y: >50 years sugarcane conventional practice; 25Y: 25 years sugarcane conventional practice; 3M: >50 years sugarcane conventional practice with recent mechanisation). For a given site, bars with the same lower case letter indicate no significant difference (P> 0.05) in native C; bars with the same upper case letter indicate no significant difference (P> 0.05) in total C.

After >50 years of sugarcane cultivation, sugarcane–derived C constituted between 31 and 68% of the existing C in topsoil (0–15 cm), the remaining 32 to 61% being attributed to native C (Table 2). The proportion of sugarcane–derived C decreased with depth in the humid and superhumid soils, but was more uniformly distributed in the 50 cm profile of the subhumid zone. Roots constitute an important source of C in sugarcane farming systems (Suman et al., 2009) and the size and distribution of the root system is strongly influenced by the distribution and availability of soil water (Baran et al., 1974). The observed differences in distribution of sugarcane-derived C were presumably due to a lower root density in the generally water saturated layer of humid and superhumid soils at lower depths, compared to a more uniform distribution of roots down to the 50 cm depth in the subhumid soils.

Over the 50 cm profile, percent contribution of sugarcane-derived C to the total SOC stock varied from 32% at Riche Terre to 65% at Medine (Table 3). Cerri and Andreux (1990) found that sugarcane-derived C constituted 20% and 45% of the total SOC after 12 and 50 years respectively of sugarcane cultivation in a Brazilian Ferralsol. The data in Figure 2 suggest that accretion of
sugarcane-derived C was dependent on the amounts of original C lost and tended to continue until the initial level of SOC is restored.

The effects of period of sugarcane cultivation on SOC changes were studied at Medine and Riche Terre. At Medine, SOC declined by 33% (33.5 t C/ha) relative to the uncultivated land after 25 years of sugarcane (Table 3). With a longer period of cultivation (>50 years), native SOC declined further to reach about 31% of the initial value. Sugarcane-derived C represented about 33% of the total C stock after 25 years and increased to 65% after >50 years of sugarcane cultivation so that loss of native C was nearly totally compensated.

Table 3—Amounts of native SOC and sugarcane-derived SOC (t C/ha) under soils cropped for different lengths of time at Medine and Riche Terre.

<table>
<thead>
<tr>
<th>Cropping system</th>
<th>Native C</th>
<th>Sugarcane-C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0–15</td>
<td>15–50</td>
</tr>
<tr>
<td>Virgin soil</td>
<td>47.17a</td>
<td>54.22a</td>
</tr>
<tr>
<td>25 years</td>
<td>20.78b</td>
<td>24.68b</td>
</tr>
<tr>
<td>50 years</td>
<td>12.20b</td>
<td>18.22b</td>
</tr>
<tr>
<td>Virgin soil</td>
<td>46.39a</td>
<td>52.32a</td>
</tr>
<tr>
<td>25 years</td>
<td>31.47b</td>
<td>49.42ab</td>
</tr>
<tr>
<td>50 years</td>
<td>28.65b</td>
<td>43.88b</td>
</tr>
</tbody>
</table>

Within one site, values along the same column followed by the same letter were not significantly different at P= 0.05.

Similar results have been reported by Dominy et al. (2002) who found that sugarcane-derived C in a Cambisol in South Africa increased over time until it accounted for 61% of total SOC in the surface soil after 50 years of sugarcane cultivation. However, in their study, the newly added C did not compensate the loss of original C. At Riche Terre, on the other hand, original SOC declined at a much slower rate so that, at 25 years, 82% of the existing SOC still had the original C signature, and this value decreased only slightly to 74% after more than 50 years of cane cultivation.

The difference in loss of original C between the two sites could be attributed to the lower initial clay content at Medine (63% compared to 75% at Riche Terre), which declined further with increasing period of cane cultivation. The importance of clay-organic matter associations as a mechanism for organic matter protection has been reported by a number of authors (e.g. Hassink, 1997; Feller and Beare 1997; Dieckow et al., 2009). Carbon inputs from sugarcane represented 29% of existing SOC after 25 years and adequately replaced the loss of native C at the Medine site.

While these results demonstrate that long-term sugarcane cultivation under the conditions in Mauritius does not have any detrimental effect on overall SOC stock, they also emphasise the importance of sugarcane crop residues in the rehabilitation of SOC under intensive sugarcane cropping. Although several studies have shown the beneficial effects of sugarcane trash retention on SOC (Graham et al., 2002; Robertson and Thorburn, 2007), few studies have quantified the actual contribution of sugarcane-derived C to the total SOC stock.

Effect of mechanised sugarcane cropping on soil carbon stocks

It was expected that the physical impact caused by intensive derocking and aggressive tillage in preparation for mechanisation would lead to a decline in SOC, as this will favour microbial activity through enhanced aeration and the exposure of formerly aggregate-protected SOC fractions (Wright and Hons, 2005; Zotarelli et al., 2007). However, mechanised cropping generally had no significant effect on topsoil or subsoil SOC stocks except at Beau Champ where total SOC declined by 37 t C/ha compared to the conventional practice (Figure 1).
The change from conventional to mechanised practice at this site was also accompanied by a decrease in the clay content from 66 to 42%. The lower SOC stock in the mechanised cropping system was presumably due to the lower clay content rather than mechanisation per se. Moreover, measurements of $\delta^{13}$C natural abundance showed that land preparation activities generally did not influence the loss of native C relative to the conventional practice except at Riche Terre and Beau Champ where land under mechanised cropping lost 24 and 16 t C/ha more C than under conventional practice (Figure 2 and Table 3). Likewise, mechanised cropping generally did not impact negatively on replacement of lost carbon by sugarcane-derived C except at Beau Champ where about 20 t C/ha less sugarcane-C was incorporated relative to the conventional practice.

**Conclusion**

Using the $\delta^{13}$C natural abundance technique, this study has demonstrated that long-term sugarcane cropping under the humid tropical climate of Mauritius resulted in significant decline in native SOC. However, losses of native SOC were adequately compensated by SOC input from sugarcane crop residues and root C turnover so that total SOC stocks in the profile generally remained unchanged.

The results further emphasise the importance of trash retention in restoring SOC under sugarcane farming systems in Mauritius. The adoption of mechanised cropping in recent years did not have any detrimental effect on soil organic carbon.

**REFERENCES**


EVOLUTION DES STOCKS DE CARBONE ORGANIQUE DU SOL SOUS CULTURE DE CANNE À SUCRE EN CLIMAT TROPICAL HUMIDE A L'ILE MAURICE: RÉSULTATS DE L'ABONDANCE NATURELLE de $^{13}$C

Par

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MOTS CLÉS : Carbone Organique Du Sol, Delta $^{13}$C, Production Durable De Canne à Sucre.

Resume

Le déclin de la capacité productive des sols suite à une monoculture à long terme de canne à sucre, associé à une intensification du système de production, est devenu le problème principal de plusieurs pays producteurs de canne à sucre. Le maintien du carbone organique de sol (SOC) à des niveaux adéquats est crucial pour le fonctionnement biologique, chimique et physique des sols. Cette étude a été entreprise pour déterminer l'impact de la monoculture à long terme de canne à sucre sur les stocks de SOC, pour mesurer la perte de SOC naturel et l'augmentation de C provenant de la canne à sucre suite à l'adoption des nouvelles pratiques culturaux, notamment l'épierrage, le nivellement et la récolte mécanique. Cinq sites représentatifs des cinq principaux groupes de sol cultivés en canne à sucre à l'île Maurice ont été étudiés et un dispositif classique de parcelles appariées a été adopté. Pour chaque site, deux emplacements ayant des conditions initiales semblables ont été traités de différentes manières dans le temps, avec un emplacement représentant le sol de référence (terre vierge avec principalement une végétation de type C3) et l'autre emplacement constitué des traitements suivants (i) champs cultivés sans interruption avec de la canne à sucre pendant plus de 25 ou 50 ans sans épierrage et nivellement, (ii) champs contenant de la canne à sucre cultivée sans interruption mais épierrés et nivelés pour permettre une récolte mécanique les 3 dernières années. Sur des échantillons de sol prélevés jusqu'à une profondeur de 50 centimètres ont été analysés le C organique total, l'abondance en $^{13}$C, la densité apparente et la teneur en pierre ou refus. La culture à long terme de canne à sucre a diminué les stocks de SOC dans la couche 0–15 cm par rapport au sol vierge non cultivé, mais a augmenté C organique du sol sous-jacent, indiquant une redistribution de SOC dans les couches plus profondes du profil de sol. Sur tous les sites, les évolutions des stocks totaux de C dans le profil 0–50 centimètres, après 50 ans de culture de canne n'étaient pas significativement différentes (P<0.05) de celles relatives à la terre vierge. La culture à long terme de canne à sucre a en fait eu comme conséquence un épuisement de SOC original de 34 à 70%. Cependant, cette perte a été entièrement compensée par les entrées de C issues des résidus de canne à sucre sur tous les sites étudiés, avec pour résultat aucun changement net des stocks de SOC. De plus, l'adoption de la culture mécanisée, qui nécessite l’épierrage et le nivellement, n'a eu aucun effet néfaste sur les stocks de SOC à cause des entrées de C provenant des résidus de récolte.
CAMBIOS EN LOS CONTENIDOS DE CARBÓNó ORGÁNICO DEL SUELO RESULTANTE DEL CULTIVO DE LA CAÑA DE AZÚCAR EN EL CLIMA TROPICAL HÚMEDO DE MAURITIUS: RESULTADOS DE ABUNDANCIA NATURAL DE $^{13}$C

Por

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PALABRAS CLAVE: Carbono Orgánico del Suelo, Delta $^{13}$C, Producción Cañera Sostenible.

Resumen

LA DISMINUCIÓN en la capacidad productiva de los suelos como consecuencia del monocultivo de la caña de azúcar a largo plazo, combinada con una intensificación del sistema de producción, se ha convertido en un problema grave en varios países productores de caña de azúcar. El mantenimiento de niveles adecuados de carbono orgánico del suelo (COS) es crucial para el funcionamiento biológico, químico y físico de los suelos. Este estudio se realizó para determinar el impacto a largo plazo del monocultivo de caña de azúcar en los niveles COS y cuantificar las pérdidas de COS nativo y la acumulación de C derivado de la caña de azúcar a causa de la adopción de nuevas prácticas de manejo como la eliminación de piedras, la nivelación y la cosecha mecanizada. El estudio se realizó en cinco sitios que representan los cinco principales grupos de suelos cañeros de Mauricio mediante la utilización de un diseño de parcela pareada. En cada una de las experiencias se evaluaron dos sitios con similares características iniciales, que se desarrollaron de forma diferente, uno en representación el suelo de referencia (campo virgen con predominio de vegetación de tipo C3) y el otro que representa los siguientes tratamientos de cultivo: (i) campos continuamente cultivada con caña de azúcar por más de 25 o 50 años sin eliminación de piedras o nivelación de los terrenos, (ii) campos de caña de azúcar a largo plazo, pero que hayan sido sometidos a la eliminación de piedras o nivelación de los terrenos para la cosecha mecanizada en los últimos 3 años. Se tomaron muestras de suelo a una profundidad de 50 cm y se analizó C orgánico total, abundancia de $^{13}$C, densidad aparente y el contenido de piedra. A largo plazo el cultivo de la caña de azúcar redujo las existencias de COS en la capa superficial de 0–15 cm en comparación con el suelo virgen sin cultivar, pero aumentó de C orgánico del subsuelo lo que indica una redistribución de la COS en las capas más profundas del perfil del suelo. Cambios en las existencias de C total en el perfil de 0-50 cm, después de 50 años de cultivo de caña no fueron significativos ($P <0.05$) en comparación con la tierra virgen en todos los sitios. Los datos de mediciones de la abundancia $^{13}$C revelaron que a largo plazo, el cultivo de caña de azúcar dio lugar a un agotamiento de COS original entre el 34 al 70%. Sin embargo, esta pérdida fue totalmente compensada por la entrada C de los residuos de la caña de azúcar en todos los sitios estudiados, sin cambio neto de las cantidades de COS en el suelo. Por otra parte, la adopción de la mecanización de cultivo, lo que implica la eliminación intensiva de piedras y nivelación de los terrenos, no tiene ningún efecto perjudicial sobre las cantidades de COS, debido al ingreso del C proveniente de residuos de la cosecha.
ASSESSMENT OF CHLOROPHYLL AND LEAF RELATIVE WATER CONTENT AS INDICATORS OF DROUGHT TOLERANCE ON SUGARCANE INITIAL GROWTH

By

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Abstract

WATER deficiency is the major environmental stress that affects sugarcane production worldwide. Physiological traits associated with drought tolerance can be suitable indicators for screening of drought tolerance of sugarcane clones to reduce the negative effects on crop yield. The aim of this study was to evaluate the ability of physiological parameters to identify drought tolerant and susceptible sugarcane clones. These parameters included estimated leaf chlorophyll content via SPAD index, photosynthetic pigments (chlorophyll \(a\), \(b\), \(a + b\) and the ratio of chlorophyll \(a\)/chlorophyll \(b\)) and leaf relative water content (RWC). The experiment was carried out under greenhouse conditions. Eight clones (CP92-675, HoCP85-845, HoCP01-523, L01-283, TCP87-3388, TCP89-3505, TCP02-4620 and TCP02-4624) variable in drought tolerance were used to assess the relation between these parameters and drought tolerance. Drought stress was imposed by withholding irrigation for 21 days and then rewatering for 6 days on plants grown at 90 days after planting. The results showed that during the drought stress the parameters SPAD index, chlorophyll \(a\), \(b\), \(a + b\) and RWC showed a progressive reduction independent of clone, but the decrease was much less in CP92-675, HoCP01-523, TCP87-3388 and TCP89-3505. After rehydration, these clones recovered most rapidly from stress condition, although the initial values were not reached. HOCP85-845, TCP02-4624, TCP02-4620 and L01-283 showed a strong negative and residual effect of drought stress in terms of chlorophyll content and RWC, and L01-283’s photosynthetic apparatus was most damaged because this clone did not show response after rewatering. Among chlorophyll parameters, chlorophyll \(a / b\) ratio was little affected by water deficit in the clones HoCP01-523, TCP89-3505, TCP87-3388 and CP92-675. Results suggest that chlorophyll and RWC could be considered to differentiate between drought tolerant and susceptible clones. We concluded that clones CP92-675, HoCP01-523, TCP89-3505 and TCP87-3388 performed as tolerant, HoCP85-845, TCP02-4620 and TCP02-4624 as intermediate, and L01-283 as drought susceptible during the initial growth.

Introduction

Sugarcane is a crop of global importance and it is cultivated between the 32º North and South parallels. In many areas over the world, rainfall is not sufficient for crop supply and water deficiency can limit crop production. Depending on the deficiency level, specifically for the sugarcane crop, growth and yield can decrease and result in great socioeconomic losses (Munns, 2002).
Drought is a multi-dimensional stress, which causes various morphological, physiological and biochemical effects on plants. The identification of markers linked to drought tolerance could be a useful tool to manage and adapt the sugarcane crop to adverse conditions (Domaisingue, 1996; Blum, 1996; Jamaux et al., 1997).

The degree of limitation of yield by environmental stresses varies even among genotypes within every species (Wolfe et al., 1988; Aguilera et al., 1999). Therefore, the ability to maintain key physiological processes, such as photosynthesis during moderate drought stress, is indicative of the potential to sustain productivity under water shortage.

Some parameters can be used as reliable indicators to evaluate efficiency of the photosynthetic system and yield performance of genotypes under water deficit.

According to Schlemmer et al. (2005), the plant’s photosynthetic potential is directly proportional to the amount of chlorophyll present in the leaf tissue. Leaf relative water content (RWC) also seems to be positively correlated to the level of photosynthesis because the prevention of water stress needs a fine regulation of water loss, in order to maintain adequate CO₂ uptake (Colom and Vazzana, 2003). To our knowledge, little is known about changes in chlorophyll and relative water content under drought stress in sugarcane genotypes.

In this context, we studied the effects of water deficiency on chlorophyll and leaf relative water content of eight sugarcane clones differing in drought tolerance.

Materials and methods

Plant material and treatment

The experiment was carried out in a greenhouse belonging to Texas AgriLife Research/Texas A&M University, in Weslaco–TX–USA. We used isolated buds of eight sugarcane clones with varying drought tolerance—four tolerant varieties (HoCP85-845, HoCP01-523, TCP89-3505 and TCP02-4620) and four susceptible varieties (CP92-675, L01-283, TCP02-87-3388 and TCP02-4624).

Cane was planted in 22 L pots, filled with vermiculite-based substrate and 55 g of the NPK formula 14-14-14. During the experiment, average air temperature was 18.1–22.6°C, relative humidity was 60–70% and photosynthetic photon flux density (PPFD) was 600–800 µmol/m²/s. Plants were grown for 60 days after planting (DAP). After that period, water was not supplied for 21 days and then re-established for 6 days.

Evaluations

Physiological parameters were measured five times during the study: 0, 7, 14, 21 days after drought stress treatment (DAT) and again 7 days after relief of stress at 28 DAT.

Leaf chlorophyll content (SPAD index) was estimated nondestructively, using a SPAD-502 chlorophyll meter (Minolta Corp., Ramsey, New Jersey, USA).

This index was selected preferentially, due to the close relationship between the readings of the portable chlorophyll meter and leaf chlorophyll content (Markwell et al., 1995), and because it has been used as a reliable nondestructive tool for rapid screening for drought tolerance in sugarcane (Silva et al., 2007). The average of four measurements taken on the leaf + 1, i.e. first fully expanded leaf, from different plants in each plot was recorded.

For the evaluation of leaf chlorophyll and water content, four 1.3-diameter discs were taken from the leaf 1 of each plant with a cork borer and then stored in thermal boxes with ice.

Chlorophyll was extracted from two leaf discs submerged for 24 h in dimethyl formamide acid (DFA). The levels of \(a\), \(b\) and \(a + b\) chlorophyll and carotenoids were determined according to Porra et al. (1989), with absorbance optical analysis in spectrophotometer on wave lengths of 480, 647 and 664 nm (Beckman DU-6400). Chlorophyll \(a/b\) ratio was calculated with the values previously determined.
Both remaining discs were used to evaluate leaf relative water content (RWC). Leaf disk fresh weight (Wf) was determined within 2 h of excision. The turgid weight (Wt) was obtained after hydration in deionised water for 24 h at room temperature.

Leaf discs were quickly blotted dry and oven-dried for 48 h at 80ºC before recording the dry weight (Wd). RWC was calculated from the following equation (Matin et al., 1989):

\[
RWC = \left[ \frac{(W_f - W_d) \cdot (W_t - W_d)^{-1}}{W_t - W_d} \right] \times 100
\]

Statistics
The experimental design was a completely randomised design, arranged in 40 combinations, within a two-factor factorial 8 x 5, where the first factor consisted of eight clones and the second consisted of five evaluation dates (0, 7, 14, 21 and 28 DAT), with three replicates. Variance analysis was applied for statistical procedure. Clones and evaluation dates were compared by the Tukey test.

Results and discussion
The ANOVA revealed that estimated chlorophyll content (SPAD), leaf chlorophyll a (Chl a), leaf chlorophyll b (Chl b), total leaf chlorophyll (Chl a + b), ratio chlorophyll a/b (Chl a/b) and leaf relative water content (RWC) were significantly affected by clone (C) and evaluation date (ED). C x ED interactions were also found to be significant for all six parameters. These results are in agreement with the ones reported by Colom and Vazzana (2003) for another C4 grass, Eragrotis curvula.

Drought stressed plants showed a progressive reduction of estimated chlorophyll content (SPAD index), during drought development (Figure 1). Positive effects of clone on drought response were evidenced by different results for three groups of clones after 21 days of stress. Clones HoCP01-523, TCP89-3505, CP92-675 and TCP87-3388 had their SPAD indexes less affected by water deficit (~35.50–41.73 SPAD units), whereas clones HoCP85-845, TCP02-4620 and TCP02-4624 showed intermediate values (~17.27–26.33 SPAD units).

The clone L01-283 was the most affected by drought stress (10.10 SPAD units). During rewatering, SPAD index increased for all clones, except for L01-283, but clones from the intermediate group reached lower SPAD (~28.70–33.27 SPAD units) than clones HoCP01-523, TCP89-3505, CP92-675 and TCP87-3388 (~40.93–46.27 SPAD units).

Chlorophyll degradation is one of the consequences of drought stress and may result from sustained photo-inhibition and photo-bleaching (Long et al., 1994), and even though other plant processes, such as cell division and cell expansion, are the earliest to respond to water deficit stress (Dale, 1988), a decline in SPAD index is a sensitive and readily measurable trait that could be used to screen for stress tolerance (O’Neill et al., 2006).

Silva et al. (2007) reported that the tolerance-susceptibility classification of a clone cannot be related to the average chlorophyll content, but rather, to the extent of the chlorophyll degradation under a stressful condition.

Chlorophyll a, chlorophyll b and chlorophyll a + b showed similar results for the clones studied, either during drought stress or after water re-establishment. During drought, chlorophyll a decreased in all clones (Figure 2). After 21 days under withholding water, a significantly higher value of chlorophyll a was found in TCP 87-3388 (19.57 µg/cm²), and the lowest value in L01-283 (8.29 µg/cm²) and TCP02-4624 (8.54 µg/cm²).

All the other clones showed intermediate performance. Chlorophyll a increased during rewatering in all clones, except L01-283 which did not show any recovery. Among the clones that increased chlorophyll a, only HoCP01-523, TCP89-3505, TCP87-3388 and CP92-675 reached values close to those observed in the beginning of the experiment.
Similarly to the results for chlorophyll $a$, chlorophyll $b$ and chlorophyll $a+b$ decreased after drought for all clones. However, clones varied in degree of stress impact on chlorophyll $a$ and $a+b$ up to 21 days after water interruption and also at 6 days after water re-establishment (Figures 3 and 4). Similar results were observed by Pardo and Delgado (1989), who also reported different contents of chlorophyll $a$ and $b$ of two sugarcane clones under drought. These authors stated that the clone susceptible to drought immediately decreased chlorophyll rates. Therefore, according to the results of this work, the clone TCP87-3388 showed the lowest decrease of chlorophyll $b$ after 21 DAT (6.76 µg/cm$^2$). A lower value of chlorophyll $b$ was observed for the clone TCP89-3505 (3.49 µg/cm$^2$), but this material was not significantly different from HoCP85-845, HoCP01-523, L01-
Nevertheless, after water re-establishment, values of chlorophyll $b$ (Figure 3) and $a + b$ (Figure 4) were almost completely restored for the clone TCP89-3388. Additionally, chlorophyll $b$ and $a + b$ significantly increased for the clones HOCP01-523, CP92-675, TCP87-3505 and TCP02-4620. The clones HOCP85-845 and TCP02-4624 had intermediate restoration of chlorophyll values. Irreversible damage can be caused by drought in the integrity of photosynthetic pigments, and this was evidenced in the clone L01-283 that did not show any recovery after water re-establishment. Colom and Vazzana (2003) reported drought affecting chlorophyll content in leaves of *Eragrotis curvula* and the susceptible clone showed the largest reduction.

![Fig. 3](image1.png)

**Fig. 3**—Mean chlorophyll $b$ ($n = 3$, ±S.E.) measured at 0, 7, 14, 21 and 28 days after onset of the drought experiment in eight sugarcane clones.

![Fig. 4](image2.png)

**Fig. 4**—Mean chlorophyll $a + b$ ($n = 3$, ±S.E.) measured at 0, 7, 14, 21 and 28 days after onset of the drought experiment in eight sugarcane clones.

Chlorophyll $a / b$ ratios responded distinctively depending on the clones under water deficiency (Figure 5). The clones HoCP01-523, TCP89-3505 and CP92-675 showed constant results, around 3.0–3.5 during all the period. For the clones HoCP85-845 and TCP87-3388, this
ratio was constant up to 14 DAT, and slightly decreased, up to 21 DAT, to about 2.8–3.0, increasing after water re-establishment, until reaching the initial values. As for the clones TCP02-4620 and TCP02-4624, the ratio was also constant up to 14 DAT, but decreased to 2.0 between 14 and 21 DAT.

![Graph](image)

**Fig. 5**—Mean ratio chlorophyll \(a\)/chlorophyll \(b\) (\(n = 3, \pm S.E.\)) measured at 0, 7, 14, 21 and 28 days after onset of the drought experiment in eight sugarcane clones.

The clone L01-283 showed chlorophyll values similar to the initial ones up to 7 DAT, decreasing to 2.0 between 7 and 21 DAT, and values increased after water re-establishment up to the initial value. According to the results, it is possible to infer that tolerant clones show a mechanism of defence against drought, keeping chl \(a\)/chl \(b\) ratio about 3.0–3.5. A second group of clones show this ratio up to 14 DAT, and they could be considered intermediately tolerant. The sensitive clones would be the ones that do not show the established values during drought.

Contradictory results can be found in literature, in relation to effects of water deficiency on the chlorophyll \(a\)/\(b\) ratio. Pardo and Delgado (1989) concluded that the chl \(a\)/chl \(b\) ratio decreased for sugarcane clones that were tolerant to drought due to an increase in the chlorophyll \(b\) content, as a possible mechanism of defence. Other authors showed that this ratio was not affected neither for tolerant nor susceptible clones of *Eragrostis curvula* under water deficiency (Colom and Vazzana, 2003).

RWC reduced as drought evolved, but the response differed among clones (Figure 6). After 21 DAT, the clone HoCP01-523 showed lower decrease in RWC values (81.2%), followed by the TCP89-3505 (78.5%) and HoCP85-845 (76.5%).

Lower values were observed for the clones L01-283 (60.3%) and TCP02-4624 (63.5%). During water re-establishment, RWC values increased for all clones. The clones HoCP01-523, HoCP85-845, TCP02-4620, TCP89-3505 and TCP87-3388 reached the values reported before drought. The clones CP92-675 and TCP02-4624 intermittently restored the original values, whereas, L01-283 showed the lowest results (70.6%).

The characteristic of maintaining a higher amount of water in the leaves during drought results in higher tolerance for some clones, because the higher capacity of saving water does not limit the CO\(_2\) absorption so much and, consequently, the efficiency of the photosynthetic process, due to better preservation of the integrity of the PSII system (Maxwell and Johnson, 2000). Then, it can be inferred that the clones with lower decrease in the RWC and higher capacity to restore the
initial conditions after water re-establishment can be considered tolerant. Besides, Silva et al. (2007) reported that drought tolerance was found to be positively correlated to RWC in sugarcane under drought conditions. Therefore, this parameter might be used as a selection criterion to differentiate sugarcane clones under drought stress.

The present study showed that it is possible to distinguish sugarcane clones under water deficiency conditions during initial growth measuring chlorophyll and leaf relative water content. Therefore, these traits could be considered as useful tools during the crop breeding procedure in order to make this process faster and cheaper. Besides, this information should be used in hybridisation programs to find parents with greater ability to transfer drought tolerance genes as expressed in different agronomic traits.

In conclusion, according to the results of this experiment, it was possible to separate the eight clones studied into three groups. The clones CP92-675, HoCP01-523, TCP89-3505 and TCP87-3388 showed lower chlorophyll degradation and higher capacity to preserve water in the leaves during the initial growth; so, they can be considered as tolerant to drought. The clones HoCP85-845, TCP02-4620 and TCP02-4624 were intermediately tolerant, whereas, the L01-283 was susceptible to drought due to irreversible chlorophyll degradation.

Acknowledgements

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ÉVALUATION DE LA CHLOROPHYLLE ET DE LA TENEUR EN EAU RELATIVE DES FEUILLES COMME INDICATEURS DE LA TOLÉRANCE A LA SÉCHERESSE SUR LA CROISSANCE PRECOCE DE LA CANNE À SUCRE

Par

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MOTS-CLÉS: Saccharum spp., Stress Hydrique, Indice SPAD, Pigments Photosynthétiques, RWC.

Résumé

Le manque d’eau est le stress environnemental principal qui affecte la production de canne à sucre dans le monde entier. Les caractéristiques physiologiques directement liées au stress hydrique sont des indicateurs appropriés pour le criblage de variétés de canne à sucre tolérantes à la sécheresse. Le but de cette étude était d’évaluer la capacité de ces paramètres physiologiques à identifier des variétés de canne tolérantes ou sensibles à la sécheresse. Ces paramètres incluaient la teneur estimée en chlorophylle des feuilles à l’aide de l’indice SPAD, les pigments photosynthétiques (chlorophylles $a$, $b$, $a + b$ et le rapport $a/b$) et la teneur en eau relatives des feuilles (RWC). L’expérience a été effectuée sous serre. Huit variétés (CP92-675, HoCP85-845, HoCP01-523, L01-283, TCP87-3388, TCP89-3505, TCP02-4620 et TCP02-4624) de tolérance variable à la sécheresse ont été employées pour évaluer la relation entre ces paramètres et tolérance de sécheresse. Sur des cannes plantées âgées de 90 jours, un stress hydrique fut appliqué en arrêtant l’irrigation pendant 21 jours, puis en puis en irrigant de nouveau pendant 6 jours. Pendant le stress hydrique, une diminution progressive de l’indice de SPAD, des chlorophylles $a$, $b$, $a + b$ et du RWC a été observée quelque soit la variété. Cependant la diminution fut moindre pour les variétés CP92-675, HoCP01-523, TCP87-3388 et TCP89-3505. Après réhydratation, ces 4 variétés récupérèrent plus rapidement, bien que les valeurs initiales des paramètres ne furent pas atteintes. HoCP85-845, TCP02-4624, TCP02-4620 et L01-283 ont montré un effet négatif et résiduel élevé du stress hydrique en termes de teneur en chlorophylle et RWC. Le système photosynthétique de L01-283 fut le plus endommagé, cette variété n’ayant pas montré de réponse lors de la remise en eau. Parmi des paramètres liés à la chlorophylle, le rapport des chlorophylles $a/b$ a été peu affecté par le stress hydrique chez les variétés HoCP01-523, TCP89-3505, TCP87-3388 et CP92-675. Ainsi la chlorophylle et RWC pourraient être considérés comme des paramètres capables de différencier des variétés sensibles et tolérantes à la sécheresse. Nous en avons conclu que les variétés CP92-675, HoCP01-523, TCP89-3505 et TCP87-3388 étaient tolérantes, HoCP85-845, TCP02-4620 et TCP02-4624 intermédiaires, et L01-283 sensible à la sécheresse pendant la croissance initiale.
EVALUACIONES DE CLOROFILA Y CONTENIDO RELATIVO DE AGUA EN LA HOJA COMO INDICADORES DE TOLERANCIA A LA SEQUÍA DURANTE EL CRECIMIENTO INICIAL DE LA CAÑA

Por

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PALABRAS CLAVE: Saccharum spp., Stress Hídrico, Índice SPAD, Pigmentos Fotosintéticos, RWC.

Resúmen

LA DEFICIENCIA de agua es el estrés ambiental más importante que afecta a la producción mundial de caña de azúcar. Las características fisiológicas asociadas con la tolerancia a la sequía pueden ser usadas como indicadores de la tolerancia a la sequía de los clones de caña de azúcar y de esta manera reducir los efectos negativos sobre el rendimiento del cultivo. El objetivo de este estudio fue evaluar la utilidad de usar parámetros fisiológicos para identificar clones de caña de azúcar tolerantes y susceptibles a la sequía. Estos parámetros incluyeron contenido estimado de clorofila en las hojas calculado por índice SPAD, pigmentos fotosintéticos (clorofila A, B, A + B y la relación de la clorofila a / clorofila b) y el contenido relativo de agua en la hoja (RWC). El experimento se llevó a cabo bajo condiciones de invernadero. Ocho clones (CP92-675, HoCP85-845, HoCP01-523, L01-283, TCP87-3388, TCP89-3505, TCP02-4620 y TCP02-4624), variables en cuanto a tolerancia a la sequía fueron utilizados para evaluar la relación entre estos parámetros y tolerancia a la sequía. El estrés hídrico fue impuesto por deprivación de riego por 21 días y posterior irrigación durante 6 días a plantas de 90 días de edad. Los resultados mostraron que durante el periodo de stress por sequía los parámetros índice SPAD, clorofila A, B, A + B y RWC mostraron reducción progresiva independientemente del clon, pero la reducción fue mucho menor en CP92-675, HoCP01-523, TCP87-3388 y TCP89-3505. Después de la rehidratación, estos clones se recuperaron más rápidamente de la condición de estrés, aunque los valores iniciales no fueron alcanzados. HOCP85-845, TCP02-4624, TCP02-4620 y L01-283 mostraron un efecto residual negativo causado por la fuerte sequía en términos de contenido de clorofila y RWC, y el aparato fotosintético de L01-283 fue el más dañado ya que este clon no mostró respuesta después del riego. Entre los parámetros de la clorofila, la relación clorofila a / b fue poco afectada por el déficit de agua en los clones HoCP01-523, TCP89-3505, TCP87-3388 y CP92-675. Los resultados sugieren que la clorofila y la RWC podrían ser considerados para diferenciar entre clones tolerantes y susceptibles a la sequía. Concluimos que los clones CP92-675, HoCP01-523, TCP89-3505 y TCP87-3388 se comportaron como tolerantes, HoCP85-845, TCP02-4620 y TCP02-4624 como intermedios, y L01-283 como susceptible a la sequía durante su crecimiento inicial.
TRASH MANAGEMENT AFTER GREEN CANE HARVESTING AND ITS EFFECT ON PRODUCTIVITY AND SOIL RESPIRATION

By

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KEYWORDS: Crop Residues, Sustainability, Soil Organic Matter, Carbon Dioxide Emission.

Abstract

A LONG-TERM trash management experiment is in progress at Cenicañas´ experiment station to evaluate the effect of continual retention of cane residues on the soil surface after green cane harvesting. The soil is a Mollisol with medium organic matter content (3.6%), high content of P (42 ppm) and K (0.46 cmol/kg) at the beginning of the study. Three trash loads of residues produced by the crop were evaluated: zero, single and double load of fresh residues were retained or removed from the soil surface of each treatment. To evaluate the nutrient supply from each load of residues, six fertiliser doses of N (0–200), P (0–75) and K (0–90) kg/ha were applied. During the plant crop, all treatments yielded close to 150 t/ha. After the eighth crop cycle, the plots without trash retention and without fertiliser application yielded 80 t/ha. The presence of residues or the application of fertilisers increased cane yield by 30 t/ha, while the combination of residues and the application of fertilisers maximised the yield up to 160 t/ha. In general, the cane yield of the trash loaded treatments tended to increase as the dosage of NPK was higher. As an indicator of soil microbial activity and crop metabolism, CO\(_2\) fluxes from the soil surface were measured just before harvest of the seventh ratoon and two more times at 75 and 93 days in the eighth ratoon crop. CO\(_2\) gas emissions from plots with single and double load of residues were three fold (303 mg/m\(^2\)/h) of the plots without trash retention (115 mg/m\(^2\)/h). The following two CO\(_2\) samplings detected lower emission rates but the pattern was similar to the sampling before harvest. From the results obtained up to now, it is concluded that higher fertiliser doses are not enough to compensate for the negative effect of residue removal from cane fields.

Introduction

The long-term maintenance of soil chemical, physical and biological fertility in soils devoted to sugarcane production depends largely on the management of the crop residues. Leaving the sugar cane residues after green cane harvesting on the soil surface, a large proportion of the nutrients removed in the biomass during the crop cycle will return to the soil. Sugarcane is a crop with high soil nutrient extraction. In the aerial biomass (leaves, leaf sheaths and stems) of the cane variety CC 85-92 under typical production conditions prevailing in Valle del Cauca, the total nutrient extraction observed was 136, 31 and 245 kg/ha of N, P and K respectively per 100 tonnes of cane stalks (CENICAÑA, 2009). From the total extraction of major elements in the aerial biomass, 57, 9 and 103 kg/ha of N, P and K stay in the field in crop residues (leaves and leaf sheaths). From a nutritional point of view, it is important to highlight the importance of the nutrient return to the soil. Nutrients in the crop residues represent 42% of N and K and 29% of P present in the total aerial biomass (leaves, leaf sheaths, and stems) to produce 100 tonnes of cane stalks in this area. Among the benefits achieved by a proper waste management are: reduction of erosion by wind
and water, increased soil organic matter (SOM), increased retention of water available to plants and increase in beneficial organisms (Andrews, 2006). Despite the benefits of keeping crop residues in the field, the effects vary between sites so, in some production systems with high incorporation of crop residues in the temperate zone, an increase in diseases and low seed germination has been reported (Linden *et al.*, 2000). A trash blanket is a positive factor in well-drained soils because better soil moisture conservation allows high water use efficiency by the crop. However, the advantage of a trash blanket can turn into a problem in areas with poorly drained soils where the trash cover can increase problems derived from waterlogging (Wood, 1991).

Increased microbial biomass is a good indicator of SOM dynamics because it responds rapidly to changes in C supply and differences can be detected as they can be measured by the total organic matter content (Gregorich *et al.*, 1997). One way to assess the soil microbial activity and root system respiration is to measure CO$_2$ emission from the ground which is a good indicator of the agro-ecosystem metabolism (Ryan and Law, 2005). It is estimated that nearly half of soil respiration is produced by metabolic activity to maintain and develop roots and associated mycorrhizae (Hanson *et al.*, 2000; Hogberg *et al.*, 2001). Most of the remainder is associated with the respiration of heterotrophic microbial communities that use organic matter as an energy substrate (Trumbore, 2000; Giardina *et al.*, 2004). Therefore, CO$_2$ emission is a good index to indirectly measure soil microbial activity and crop physiology.

Faced with the imminent stopping of the sugarcane burning practice before harvesting in Valle del Cauca, the need to know the long-term impact of sugarcane residues from green cane harvesting on the physical, chemical and biological soil fertility is crucial. In 2000, Cenicaña set up an experiment to be continued for an indefinite period, under three different management schemes of crop residues. At present, this experiment is starting its tenth cropping cycle, and this paper provides a summary of cane productivity from the plant to the seventh ratoon crop harvested and a preliminary view of SOM content.

**Material and methods**

The experiment was established in lot 19 of the Experimental Station San Antonio (EESA) of Cenicaña. The soil is classified as Cantarina (Pachic Vertic Haplustoll), fine textural family (IGAC-CENICAÑA, 2006) 6H1 agroecological zone (CENICAÑA, 2006) with pH near neutrality, medium content of SOM (3.63%) and high P content (42 ppm) and exchangeable K (0.46 cmol/kg). The sugarcane variety planted was CC 85-92. The lot was divided into three equal parts and in each of them we established three management schemes of crop residues. At present, this experiment is starting its tenth cropping cycle, and this paper provides a summary of cane productivity from the plant to the seventh ratoon crop harvested and a preliminary view of SOM content.

The experiment was established in lot 19 of the Experimental Station San Antonio (EESA) of Cenicaña. The soil is classified as Cantarina (Pachic Vertic Haplustoll), fine textural family (IGAC-CENICAÑA, 2006) 6H1 agroecological zone (CENICAÑA, 2006) with pH near neutrality, medium content of SOM (3.63%) and high P content (42 ppm) and exchangeable K (0.46 cmol/kg). The sugarcane variety planted was CC 85-92. The lot was divided into three equal parts and in each of them we established three management schemes of crop residues. All the trash was removed (TR) from one of the thirds and placed in another third to accumulate into a double load (DL) of residues arranged following a pattern of two inter-row spaces with residues and two without residues.

The last third was left with the single load (SL) of residues arranged following a pattern of two inter-rows with residues and one inter-row without residues. Each third assigned to a trash management scheme was divided in three equal areas to be used as replications. Each replication was sub-divided into six plots consisting of 10 rows of 12 metres in length, with 1.5 m between rows. In each of the plots, one of six doses of N, P and K as fertilisation treatments was applied. Three treatments consisted of three levels of N-P-K (low, medium, and high), two with the medium level of N and without P or K, and one treatment with no application of fertilisers.

The fertilisation treatments were randomised according to a complete block design within each area of residue management. Soil tillage during ratoon crops was limited to cultivation between rows to control weeds and to incorporate the fertiliser applied. Statistical analysis was done separately for each area representing a scheme of crop residues management. An analysis of variance using the mixed procedure (SAS, 2008) was performed in order to detect differences in productivity parameters under the six fertilisation treatments applied into each one of the three areas with different trash management schemes.
Fertilisation treatments were applied 45 days after planting or harvest with the exception of P and K which were applied to the bottom of the row before plant cane sowing. Population density and stem height were evaluated at 3, 4.5 and 6 months after planting. At the same time, leaf tissue samples were taken to evaluate foliar content of major and minor elements. Crop cycle length was about 13 months. Height of millable stalks was measured prior to harvest and a sample of millable stalks was taken to the laboratory for juice analysis. At the beginning of the experiment and after each harvest, four soil samples 0–20 cm depth were taken and bulked to represent each plot. Soil samples were analysed for pH, SOM, P, Ca, Mg, and Na. At plant cane harvest, soil texture was determined from the soil sampling.

This paper reports on cane yield (TCH), sucrose % cane (SPC) determined by the direct analysis of cane method (DAC) and soil organic matter (SOM) determined by the dichromate methodology (Walkley and Black, 1934), during eight crop cycles. Emission of carbon dioxide (CO2) from samples taken two days before the harvest of the eighth cycle, and two more at 75th and 93rd days of the ninth cycle was also recorded. Gas samples were taken in plots fertilised with 150-50-60 kg/ha of NPK inside of each one of the trash management schemes. In each of the sampled plots, 2 PVC chambers were installed (one between rows and one in-row), and a sequence of four samples of gases at intervals of 0, 10, 20 and 30 minutes were taken. Gas samples were analysed with a CO2 gas analyser with NaOH and silica gel trap.

**Results and discussion**

In areas with single (SL) and double trash (DL) loads, average TCH over the eight crop cycles resulted in lower cane production under no fertilisation treatments (Table 1). Although, in the area with a double trash load, the difference in cane production among treatments with varying fertilisation was not significant, it followed a similar pattern to cane production under single trash load where differences were significant at 6% level (Table 1). The negative effect of crop residues removal (TR) on fertiliser efficiency is evident by the no response of TCH to the increase of NPK dose and the highly significant difference among plots with fertiliser application and plots without fertiliser application (Table 1).

Under the single trash load scheme, there were no differences in TCH between plots applied with the lowest dose of NPK, plots without K application, and plots without fertiliser application suggesting a suboptimal NPK dose as limiting to cane production. Sucrose content was reduced significantly with no application of fertilisers under single and double trash loads, while no difference between fertilised and non-fertilised plots was visible under the trash removal (TR) treatment (Table 1). The trend to higher PSC observed in plots with trash removal could be attributed to crop stress due to lower use efficiency of fertilisers caused by the lack of the synergistic effect of crop residues left on the soil.

### Table 1—Cane yield (TCH), sucrose percent cane (SPC) and soil organic matter (SOM) averaged over eight crop cycles under effect of trash load and NPK doses.

<table>
<thead>
<tr>
<th>N-P-K Kg/ha</th>
<th>Single trash load (SL)</th>
<th>Double trash load (DL)</th>
<th>Trash removal (TR)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TCH</td>
<td>SPC</td>
<td>SOM</td>
</tr>
<tr>
<td>100-25-30</td>
<td>142 ac</td>
<td>12.04 a</td>
<td>3.00</td>
</tr>
<tr>
<td>150-50-60</td>
<td>153 a</td>
<td>12.46 a</td>
<td>3.09</td>
</tr>
<tr>
<td>200-75-90</td>
<td>154 a</td>
<td>12.30 a</td>
<td>3.11</td>
</tr>
<tr>
<td>150-0-60</td>
<td>150 a</td>
<td>12.38 a</td>
<td>3.29</td>
</tr>
<tr>
<td>150-50-0</td>
<td>143 a</td>
<td>12.43 a</td>
<td>3.07</td>
</tr>
<tr>
<td>0-0-0</td>
<td>131 bc</td>
<td>11.59 b</td>
<td>3.19</td>
</tr>
<tr>
<td>Sig. level</td>
<td>0.06</td>
<td>0.08</td>
<td>ns</td>
</tr>
</tbody>
</table>

Means followed by different letter are statistically different to the indicated level. Mean separation by Least Squares Means procedure.
No difference in soil organic matter (SOM) under different trash management schemes or fertiliser treatments was detected and the expected effect of trash removal on SOM was not evident (Table 1). This could be explained by the soil sampling depth used in this experiment (20 cm) and the relatively short life time (10 years). After 59 years, in the long-term experiment located at Mount Edgecombe, difference in organic carbon (OC) from plots with trash burnt before harvest and plant tops raked off (4.3% OC) and plots with green cane harvest with trash retention (5.1% OC) were evident at a depth as far as 5 cm and almost disappeared at 10 cm (Graham et al., 2002).

Based on the factors tested in this experiment, three scenarios could be defined as follows: plots without addition of crop residues or fertilisers, plots with addition of fertilisers or crop residues, and plots with addition of both fertilisers and crop residues. By plotting the results of the cane yield (TCH) under these three scenarios (Figure 1) it has been possible to describe three different situations through to the eighth ratoon crop. Plots without crop residues and without fertilisers (TR – F) had a descending trend in cane yield from about 140 t/ha at plant cane to 80 t/ha at the seventh ratoon. This clearly descendent pattern could be attributed to deterioration of chemical, physical and biological soil fertility.

Contrasting with this situation, treatments with trash and fertiliser application (SL + F and DL + F) diminished their TCH until the third ratoon crop but, after that, a clear uprising pattern was observed until the eighth ratoon crop when a similar cane yield to the plant cane was reached again. This situation shows how important for the sugarcane system to include crop residues with fertiliser addition in order to achieve a synergetic effect that allows the crop to recover productivity levels as high as those of the plant cane (Figure 1). An intermediate situation in terms of TCH was achieved when crop residues or fertilisers were applied individually (SL – F, DL – F and TR + F), cane yield decreased from 150 – 165 t/ha in plant cane to a relatively steady TCH of approximately 125 t/ha from the third to the eighth ratoon crop (Figure 1). It highlights that it is not possible to compensate the negative effect of trash removal by addition of synthetic fertilisers even when applied at higher rates. Furthermore, it was clearly demonstrated that crop residues have not just an effect on chemical fertility but they can also impact positively on physical and biological soil factors.

![Fig. 1—Cane yield (TCH) under three trash management schemes, single load (SL), double load (DL), and trash removal (TR) combined with application (+F) or not (–F) of fertilisers.](image)
Emission of CO$_2$ from plots with double and single trash load was systematically higher than that from plots with trash removal suggesting increased microbial activity and crop physiology enhanced by the crop residues left on the field during eight consecutive crops (Figure 2).

This fact is coincident with the higher crop productivity observed in plots with combined application of residues and fertilisers (Figure 1).

The downshift in emission of CO$_2$ observed 75 days after harvest as compared with the emission rate observed just before harvest could be mainly due to decreased root respiration caused by the interruption of all physiological crop processes after cane cutting (Figure 2).

After cane harvest, a renewed root system starts growing during the succeeding ratoon and this was reflected by the gradual increase of CO$_2$ emission rate observed between the 1$^{st}$ and 19$^{th}$ of June (Figure 2).

Higher CO$_2$ emission from plots with combined trash and fertiliser application (Figure 2) was expected because their higher biomass production (Figure 1) and increased C input by trash application as compared with plots where trash removal was done.

The beneficial effect of crop residues from sugarcane on soil health and crop productivity is shown by the results of this experiment. Under the environmental conditions of this experimental site, it was observed that productivity and sustainability of the system in terms of TCH, was achieved only with treatments where trash was left on the ground and additional fertiliser was applied.

Until the eighth ratoon crop, individual application of crop residues or fertilisers even at high rates, were not sufficient to match the productivity of plots in which fertilisers and crop residues were applied simultaneously.

In plots with trash removal without fertiliser application, productivity declined significantly. This experimental site will be maintained and monitoring will continue indefinitely in order to quantify the long-term effect of continuous addition of crop residues after green harvesting on sugarcane production and soil health.
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GESTION DU PAILLIS APRÈS LA RECOLTE DE CANNE VERTE ET SON EFFET SUR LA PRODUCTIVITÉ ET LA RESPIRATION DU SOL

Par

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MOTS-CLÉS: Résidus de Récolte, Durabilité, Matière Organique du Sol, Émission de Dioxide de Carbone.

Abstract
UNE EXPÉRIENCE à long terme concernant la gestion du paillis a été entreprise sur la station expérimentale de Cenicañas pour évaluer l'effet de la conservation des résidus de récolte sur la surface du sol après la récolte en vert de la canne. Le sol est un Mollisol comportant un taux moyen de matière organique (3.6%), une teneur élevée en P (42 ppm) et en K (0.46 cmol/kg) au début de l'étude. Trois doses de paillis produit à la récolte ont été évaluées : aucun paillis, deux doses simple et double de résidus frais ont été enlevées ou maintenues à la surface du sol sur chaque traitement. Pour évaluer l'apport nutritif de chaque dose des résidus, six doses d'engrais en kg/ha de N (0-200), de P (0-75) et de K (0-90) ont été appliquées. En canne plantée, tous les traitements ont produit à peu près 150 t/ha. Après le huitième cycle de récolte, les parcelles sans paillis et sans application d'engrais ont produit 80 t/ha. La présence des résidus ou l'application des engrais a augmenté le rendement en canne de 30 t/ha. L'association des résidus et des engrais ont produit des rendements maximum atteignant 160 t/ha. Généralement les rendements des traitements avec paillis étaient supérieurs car la dose effective de NPK était plus élevée. Comme indicateur d'activité de sol et du métabolisme microbien, les flux de CO2 provenant de la surface du sol ont été mesurés juste avant la récolte de la septième repousse et 75 et 93 jours après cette récolte. Avant récolte, les émissions de CO2 des parcelles ayant reçu des doses simple et double de paillis furent trois fois supérieures (303 mg/m²/h) à celles des parcelles sans paillis (115 mg/m²/h). Les deux prélèvements suivants ont révélé des taux inférieurs d'émission de CO2 mais avec des rapports identiques à ceux mesurés avant récolte. Des résultats obtenus jusqu'ici, on peut conclure que les doses plus élevées d'engrais ne sont pas suffisantes pour compenser l'effet négatif de l'enlèvement des résidus.

MANEJO DE LOS RESIDUOS DE COSECHA EN VERDE Y SU EFECTO SOBRE PRODUCTIVIDAD Y RESPIRACIÓN DEL SUELO

Por

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PALABRAS CLAVE: Residuos de Cosecha, Sostenibilidad, Materia Orgánica del Suelo, Emisión de Dióxido de Carbono.

Resúmen
UN EXPERIMENTO a largo plazo sobre manejo de residuos está en marcha en la estación experimental de Cenicaña para evaluar el efecto de la retención o remoción continua de los residuos de cosecha en verde de la caña. El suelo es un Mollisol con contenido medio de materia orgánica (3.6%), altos contenidos de P (42 ppm) y K (0.46 cmol/kg) medidos al comienzo del estudio. Tres cantidades de residuos producidos por el cultivo fueron evaluadas: remoción total, carga sencilla y carga doble de residuos frescos fueron aplicados al suelo en cada tratamiento. Durante la plantilla,
todos los tratamientos produjeron alrededor de 150 t/ha de caña. Después de la octava soca, las parcelas sin residuos y sin aplicación de fertilizantes produjeron 80 t/ha. La presencia de residuos o la aplicación de fertilizantes incrementó la producción de caña en 30 t/ha, mientras la combinación de residuos y la aplicación de fertilizantes maximizó la producción hasta 160 t/ha. En general, la producción de caña de los tratamientos con retención de residuos tendió a incrementarse cuando la dosis de NPK fue más alta. Los flujos de CO₂ desde la superficie del suelo fueron medidos justo antes de la cosecha de la séptima soca y dos veces más a los 75 y 93 días de la octava soca. La emisión de CO₂ desde las parcelas con carga sencilla y doble de residuos fue casi el triple (303 mg/m²/h) de la de las parcelas sin residuos (115 mg/m²/h). En los siguientes dos muestreos se detectaron tasas de emisión menores pero el patrón fue similar al del muestreo de antes de la cosecha. De los resultados obtenidos hasta ahora, se concluye que altas dosis de fertilización no son suficientes para compensar el efecto negativo de la remoción de residuos de los campos de caña.
EFFECTS OF LOCATION AND TIME OF HARVEST ON YIELDS OF THE THREE MAIN SUGARCANE VARIETIES IN MEXICO

By

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KEYWORDS: Sugarcane, Harvest Scheduling.

Abstract

In México, during the past three years, a mean 650 000 hectares of sugarcane were cultivated, which delivered more than 46.5 Mt of cane with a maximum commercial cane sugar content of 11.43 to 57 sugar mills, distributed throughout the Pacific Ocean Coast, a transversal belt around parallel 19 and the Mexican Gulf Coast. In this diversity of climates and soils, more than 20 varieties are cultivated, but approximately 65% of the area is planted with three varieties: Mex 69-290, CP 72-2086 and Mex 79-431. In order to determine accurately the effects of time of harvest on these three varieties for optimum harvest scheduling, two field trials were planted in October 2003, with the three varieties mentioned above in two highly contrasting localities in climate and soil, within the country's main sugarcane region. The trials were harvested at six times during the December/2004 – May/2005 harvest season. In the dry zone, cane yield was highest early in the harvest season, in December, January and February, while yields declined from March. In contrast, in the moist zone, the harvest season began with a trend of low cane yields in December and January, reached a maximum in February and March, and again declined during April and May. Reducing sugars in the dry zone showed, in CP 72–2086, low values early in the harvest season, which began to increase significantly in March and maintained high values until the end of the harvest season in May; Mex 69–290 recorded high values in December, which decreased in January, February and March, and increased again in April and May; while Mex 79–431 maintained low values from December to March, with a trend to increase from April. The principal components analysis demonstrated the important effects of locations on cane and sugar yields and time of harvest, the influence of the environment on varietal yields, and verified the dependence of cane yield on its components stalk population, length and diameter. Negative correlations between yield component variables and moisture, reducing sugars and fibre were also found.

Introduction

Nationwide sugarcane cultivation in Mexico occupies approximately 650 000 ha, with an average cane yield of 70.43 t/ha. The State of Veracruz is the largest cane and sugar producer, comprising 22 sugar mills, which crushed 17 797 093 tonnes of cane, with a total sugar output of 1 991 991 tonnes in the 2006–2007 harvest season.

El Potrero Sugar Mill stands out for its high factory efficiency, processing 1 477 426 tonnes of cane, in an area of 20 788 ha, with a sugar output of 187 821 tonnes, thus generating significant economic activity in the region (Manual Azucarero Mexicano, 2008). Two main sugarcane agro-ecological regions can be distinguished in El Potrero: the critical (dry) rainfed zone and the moist rainfed zone.
The main varieties cultivated in the ‘El Potrero’ mill supply area, according to maturity period, are as follows: early-season CP 72 2086 (26.54%), CP 44-101 (9.23%), and others (6.26%); and intermediate-season: Mex 69-290 (36.23%), Mex 79-431 (8.25%), Mex 68 P-23 (4.54%), and others (8.95%) Thus the El Potrero acreage consists of 42.03% of early-ripening and 57.97% of intermediate–ripening varieties. The two main varieties in the ‘El Potrero’ mill supply area are: Mex 69-290 and CP72-2086, which represent 62.77% of the sugarcane cultivated land, hence the need to study the influence of age and time of harvest of these varieties on cane and sugar yields, in the two agro-ecological zones that exist in the mill's supply area.

Materials and methods

General aspects of the trials

The experimental work was carried out in two locations of the ‘El Potrero’ sugar mill, a dry zone, with annual rainfall below 1100 mm, and a moist zone, with approximately 1900 mm of rainfall. The three main varieties grown in the mill areas: CP 72-2086, Mex 69-290 and Mex 79-431, were used in the plant cane cycle. The trials were planted in the two locations in October 2003 and were harvested at six different times from December 2004 to May 2005.

Location 1: Dry zone

Trial 1 was planted at Barrabas Farm located at 19º01’6.5’ N 96º33’58.3’ W, at 260 metres above sea level, in the central zone of the State of Veracruz,. The climate type at this location is Aw 1 (w) warm sub-humid, intermediate between Aw0 and Aw2, with a R/T (index which results from dividing annual rainfall, expressed in millimetres, by the annual mean temperature in °C) between 43.2 and 55.3, and a percentage of winter rainfall below 5.

Maximum temperature averages 31.35°C, and minimum temperature 19.6°C with a mean temperature of 25.7°C, and a mean annual rainfall of 1085 mm. (Irrigation Department, 2008). The trial was planted on Vertisol soil.

Location 2: Moist zone

Trial 2 was planted in the municipality of Atoyac, located in the central, mountainous zone of the State of Veracruz, at 18º53’42.1’ N and 96º47’12.4’ W, at an altitude of 511 metres above sea level.

The climate is warm-moist-regular, with a maximum temperature of 29.73°C, a minimum temperature of 18.99°C and a mean temperature of 24.59°C. Mean annual rainfall is 1866 mm. The trial was planted in an Acrisol type soil (Irrigation Department, 2008).

Varieties studied

CP 72-2086 (Parents: CP 62-374 X CP 63-588)

CP 72-2086 has recorded good germination and tillering, fair trashing, and early and heavy flowering. Mean cane yields of CP 72-2083 were 102 and 90.6 t/ha in plant cane and ratoon, respectively (Marin and Velasquez, 1997; Flores, 2001).

Its mean sucrose (pol) percent cane is 14.49% and the fibre content is 13.1%. It is resistant to Smut and Rust, moderately resistant to Mosaic, and susceptible to stem borer attack and to Orange Rust.

Mex 69 290 (parents: Mex 56-476 X Mex 53-142)

Mex 69-290 has recorded fair germination, early tillering and good growth, and fair trashing. Its leaves remain attached to the stalk and are easily removed by hand. It is resistant to lodging, but susceptible to stalk breakage by strong winds.

Mex 69-290 exhibits little or scarce flowering, and is suited for regions with irrigation and rainfed conditions with annual rainfall above 1500 mm and altitude from 0 to 800 metres above sea level. Average cane yields have been 102 t/ha in plant cane, and 92 t/ha in ratoon (Marin and Velasquez, 1997; Flores, 2001). It is resistant to Smut, Rust and Red Streak, susceptible to Pokkah-Boeng and Eye Spot, and tolerant to mealy bug and to stem borer.
Mex 79-431 (parents: Co 421 X Mex 57-473)

Mex 79-431 has recorded good germination and tillering, and good agronomic appearance, even under adverse drought conditions. Ratooning is excellent. It exhibits scarce to fair flowering, with highest percentages occurring in intermediate altitudes and not at higher altitudes or at sea level. It exhibits fair thrashing.

Cane yields in trials in plant cane and ratoon are 193 and 173 t/ha, respectively, under irrigated experimental conditions (Marin and Velasquez, 1997; Flores, 2001).

In locations with high humidity, it is susceptible to Eye Spot disease and occasional symptoms of Mosaic (SCMV) have been observed.

**Trial layout and treatments**

A sub-split plot factorial arrangement ($2 \times 3 \times 6$) was used in a randomised block design with four replicates. The experimental plots consisted of six rows 12 m long, spaced at 1.15 m and with an area of 82.8 m$^2$, with a net plot of four central 12 m long rows, equivalent to 55.2 m$^2$.

Experimental factors under study were the following.

a) Location: dry zone (L1) and moist zone (L2).

b) Variety: CP 72-2086 (V1), Mex 69-290 (V2) and Mex 79-431 (V3).

c) Month of harvest: December (M1), January (M2), February (M3), March (M4), April (M5) and May (M6).

**Measurements**

Temperature and rainfall were measured at intervals throughout the trials. Soil fertility variables (organic matter, total nitrogen, potassium, phosphorus, micronutrients, clay, silt and sand contents, acidity (pH) and Base Exchange Capacity) were measured to a depth of 30 cm at the two locations.

Sugarcane germination percentage, stalk length, diameter and population at six months of age and prior to each harvest date were measured, as well as cane yield, stalk fibre and moisture, juice purity, brix and reducing sugars, sucrose (pol) and theoretical sugar yield per hectare at harvest were determined, according to established methodologies (IMPA, 1983).

The data collected were analysed by ANOVA, regression and main components analyses, using the SAS system for Windows, release 6.12 (SAS Institute Inc. 1989–1996) and the Principal Components Analyses following the methodology described by Pla (1986) and (Bilodeau and Brenner, 1999), without repeated analyses of the data.

**Results**

**Climate**

In the moist zone (Trial 2), rainfall was 1162 mm greater than that of the dry zone (Trial 1), (Table 1), which indicates a better sugarcane growth in the former than the latter and therefore higher potential cane yields and less deterioration from untimely harvesting, which was one of the factors under study in both zones.

Temperatures in the dry zone were higher than those of the moist zone by 1.62°C, 1.11°C and 0.61°C for maximum, mean and minimum, respectively. In the dry zone, not only did it rain less, but also temperatures were much higher.

**Physical-chemical characteristics of the soils of the studied localities**

As shown in Table 2, the physical-chemical characteristics of the soils of locations were adequate for sugarcane cultivation, but in the case of the dry zone, a greater number of growth limiting factors were present (Arcia, 1997), as indicated by low phosphorus and potassium content and intermediate organic matter content, which implies the need for supplementary applications of these nutrients to the soil for sugarcane production.
Table 1—Rainfall and temperature during October, 2003, to May, 2005, at the two trial locations.

<table>
<thead>
<tr>
<th>Months</th>
<th>Moist zone</th>
<th>Dry zone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rainfall mm</td>
<td>Temperatures °C</td>
</tr>
<tr>
<td></td>
<td>Max Mean Min</td>
<td>Max Mean Min</td>
</tr>
<tr>
<td>October 2003</td>
<td>146 28.7 24.4 20.2</td>
<td>28 34 28 22</td>
</tr>
<tr>
<td>November</td>
<td>105 27.2 23.4 19.6</td>
<td>117 29 23 17</td>
</tr>
<tr>
<td>December</td>
<td>12 24.3 18.7 13.1</td>
<td>23 28 23 17</td>
</tr>
<tr>
<td>January 2004</td>
<td>29 25.6 20.5 15.4</td>
<td>13 29 24 18</td>
</tr>
<tr>
<td>February</td>
<td>20 26.8 20.8 14.8</td>
<td>13 30 24 17</td>
</tr>
<tr>
<td>March</td>
<td>12 29.4 24.2 19.0</td>
<td>1 31 25 19</td>
</tr>
<tr>
<td>April</td>
<td>143 30.8 25.4 19.9</td>
<td>78 36 27 18</td>
</tr>
<tr>
<td>May</td>
<td>112 32.0 26.7 21.4</td>
<td>68 35 28 20</td>
</tr>
<tr>
<td>June</td>
<td>482 31.8 30.9 20.0</td>
<td>167 36 29 22</td>
</tr>
<tr>
<td>July</td>
<td>122 32.2 26.4 20.7</td>
<td>102 32 26 20</td>
</tr>
<tr>
<td>August</td>
<td>364 33.9 27.6 21.4</td>
<td>218 35 29 22</td>
</tr>
<tr>
<td>September</td>
<td>161 31.8 26.2 20.6</td>
<td>151 34 27 19</td>
</tr>
<tr>
<td>October</td>
<td>167 33.8 28.3 22.9</td>
<td>78 30 27 24</td>
</tr>
<tr>
<td>November</td>
<td>78 28.3 23.3 18.3</td>
<td>17 29 24 19</td>
</tr>
<tr>
<td>December</td>
<td>13 26.9 21.7 16.5</td>
<td>4 26 22 17</td>
</tr>
<tr>
<td>January 2005</td>
<td>2 28.4 22.2 16.1</td>
<td>4 27 22 17</td>
</tr>
<tr>
<td>February</td>
<td>56 27.7 23.1 18.5</td>
<td>15 27 23 19</td>
</tr>
<tr>
<td>March</td>
<td>21 29.3 24.1 19.2</td>
<td>12 29 25 20</td>
</tr>
<tr>
<td>April</td>
<td>50 33.0 26.7 20.4</td>
<td>2 34 29 23</td>
</tr>
<tr>
<td>May</td>
<td>265 32.7 27.2 21.8</td>
<td>87 36 29 22</td>
</tr>
<tr>
<td>Mean</td>
<td>2 360</td>
<td>1 198</td>
</tr>
</tbody>
</table>

Table 2—Characterisation of soil physical-chemical properties, at 0 to 30 cm depth in the trial sites, El Potrero Sugar Mill, Veracruz, Mexico.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Dry zone 0 – 30 cm depth</th>
<th>Moist zone 0 – 30 cm depth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Classification</td>
<td>Classification</td>
</tr>
<tr>
<td>Organic matter (%)</td>
<td>2.44 Intermediate</td>
<td>4.27 Rich</td>
</tr>
<tr>
<td>Total Nitrogen (%)</td>
<td>0.18 Rich</td>
<td>0.28 Very rich</td>
</tr>
<tr>
<td>Phosphorus mg/kg</td>
<td>12.78 Low</td>
<td>131.02 High</td>
</tr>
<tr>
<td>Potassium mg/kg</td>
<td>140.0 Low</td>
<td>350.0 High</td>
</tr>
<tr>
<td>pH in KCL</td>
<td>5.38 Moderately acid</td>
<td>5.92 Moderately acid</td>
</tr>
<tr>
<td>pH in water</td>
<td>6.05 Moderately acid</td>
<td>6.31 Moderately acid</td>
</tr>
<tr>
<td>Ca</td>
<td>13.362 High</td>
<td>5.075 Intermediate</td>
</tr>
<tr>
<td>BEC (cmol/kg) Mg</td>
<td>2.579 Intermediate</td>
<td>3.361 High</td>
</tr>
<tr>
<td>K</td>
<td>0.486 Intermediate</td>
<td>0.563 Intermediate</td>
</tr>
<tr>
<td>Fe (mg/kg)</td>
<td>28.60 Very high</td>
<td>56.80 Very high</td>
</tr>
<tr>
<td>Cu (mg/kg)</td>
<td>1.40 High</td>
<td>12.00 Very high</td>
</tr>
<tr>
<td>Zn (mg/kg)</td>
<td>0.60 Very low</td>
<td>6.40 High</td>
</tr>
<tr>
<td>Mn (mg/kg)</td>
<td>30.0 High</td>
<td>208.0 Very high</td>
</tr>
<tr>
<td>Sand %</td>
<td>28.20 Silty-sand</td>
<td>32.20 Silty</td>
</tr>
<tr>
<td>Silt %</td>
<td>39.28 Silty</td>
<td>43.28 Silty</td>
</tr>
<tr>
<td>Clay %</td>
<td>32.52</td>
<td>24.52</td>
</tr>
</tbody>
</table>
Performance of agricultural and quality variables at harvest

Analyses of variance of agricultural variables (cane population, length, diameter and yield) and quality variables (fibre, moisture, reducing sugars, sucrose and tonnes of sugar per hectare) at harvest (Table 3) were carried out, as well as their respective comparisons of means of the most important interactions (Table 4).

Cane yield

There were highly significant differences between locations, varieties, months of harvest and in the interactions location by variety and location by month of harvest (Table 3). By comparing the means of these main effects and their interactions (Table 4) it can be observed that cane yield was significantly higher in the moist zone in all three varieties under study, which demonstrates the effect of the location on the performance of the varieties, and confirms reports by Mariotti (1987) in Argentina, Ghaderi et al. (1980) in India and Bernal (1986) in Cuba.

By reviewing the interaction location by month of harvest, it can be noticed that, in the dry zone, cane yield was highest early in the season in December, January and February, and from March there was a decline in cane yield, which became significantly lower in April and May. In contrast, in the moist zone, the cane yield trend was toward low yields in December and January, which then increased to a maximum in February and March, and later decreased during the months of April and May. This clearly shows the need to take into consideration the characteristics of the locations in order to optimise harvest scheduling (Milanes et al., 2007).

Percentage of reducing sugars

Highly significant differences were determined (Table 3) between locations, varieties, months of harvest and the interactions location by variety, location by month of harvest and location by variety by month of harvest in percent reducing sugars.

By comparing the means of these main effects and their interactions (Table 4) it can be observed that reducing sugars (Table 4 and Figure 1) show a different time curve for each variety. Thus, CP 72–2086 recorded low reducing sugar values at the beginning of the harvest season, which increased significantly in March, and maintained these values until the end of the harvest season in May.

Variety Mex 69–290 began harvest with high values in December, then decreased during January, February and March, and again increased in April and May. Variety Mex 79–431 recorded high values in December and January, which reduced significantly in February and March, and later increased significantly in April and May.

The results recorded suggest that variety CP72-2086 should be harvested at the beginning of the harvest season and finalised before March, variety Mex 69-290 should be harvested preferably during the months of January, February and March, while variety Mex 79-431 has best harvest timing in February and March.

Table 3—Results of the analyses of variance of variables assessed at harvest.

<table>
<thead>
<tr>
<th>S.V.</th>
<th>popul.</th>
<th>length</th>
<th>diam.</th>
<th>yield</th>
<th>fibre</th>
<th>moisture</th>
<th>re. su.</th>
<th>suc.</th>
<th>tst/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rep.</td>
<td>*</td>
<td>*</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>L</td>
<td>**</td>
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<tr>
<td>V</td>
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<td>NS</td>
<td>NS</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>L*V</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>L*M</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>V*M</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>**</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>L+V*M</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>**</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>C.V.</td>
<td>7.47</td>
<td>6.73</td>
<td>3.38</td>
<td>12.67</td>
<td>5.46</td>
<td>1.16</td>
<td>1.12</td>
<td>4.16</td>
<td></td>
</tr>
</tbody>
</table>

* = P≤0.05, ** = P≤0.01
S.V.: Source of variation; L: location; V: variety; M: month of harvest; C.V.: coefficient of variation; re. su.: reducing sugars % juice; suc.: sucrose % cane; tst/ha: tonnes theoretical sugar per hectare.
Principal Components Analyses
Components and eigenvectors

As can be noticed in Table 5, the first four components extracted more than 90% of the total variation of the assessed matrix, and the first two reached 72.72%; consequently, it is considered sufficient to work with the information that these two components extracted. In the first component the important variables were: locality, cane yield, stalk population, stalk length, stalk diameter, fibre, reducing sugars, sucrose and tonnes of theoretical sugar per hectare, and in the second component: juice purity and cane moisture were the most important, with opposite signs, this is, with contrary effects, as expected. It is noticeable that the variables associated with yield components had the same sign as did localities, hence the great effect of the former on cane yield. On the other hand, the effect of reducing sugars is contrary to that of sucrose, almost with the same values of components, but with opposite signs; similar results have been reported by Bernal (1986) and Milanes et al. (2007).

Relationships and importance of the variables

In the correlation circle (Figure 2), it can be noticed that the effects of variables which are cane yield components are directly opposite to the effect of fibre and reducing sugars, while sucrose and juice purity are associated and opposite to stalk moisture, which logically happens. Supplementary variables show little importance, except locations, also in this case related to the cane yield components.

Behaviour of individuals

In the case of individuals, in a chart, components 1 and 2 have been displayed, and the grouping of the 108 studied individuals into two large groups (Figure 3) is noticeable. The components are associated with each of the two studied locations, which confirms the importance of this factor in the performance of the sugarcane crop.

Table 4—Comparison between means of the most important significant interactions at harvest.

<table>
<thead>
<tr>
<th>No.</th>
<th>Location x variety interactions</th>
<th>Location x variety x month of harvest interactions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>Cane yield (t/ha)</td>
</tr>
<tr>
<td>1</td>
<td>L₁ x V₁ (Dry zone)</td>
<td>49.94 b</td>
</tr>
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<td>2</td>
<td>L₁ x V₂ (Dry zone)</td>
<td>46.36 b</td>
</tr>
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<td>3</td>
<td>L₁ x V₃ (Dry zone)</td>
<td>48.84 b</td>
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<td>4</td>
<td>L₂ x V₁ (Moist zone)</td>
<td>118.64 a</td>
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<td>6</td>
<td>L₂ x V₃ (Moist zone)</td>
<td>137.73 a</td>
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<td>Standard error</td>
<td>21.19</td>
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<td></td>
<td>Locality x month of harvest</td>
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<tr>
<td>1</td>
<td>L₁ x M₁ (Dry zone)</td>
<td>56.42 c</td>
</tr>
<tr>
<td>2</td>
<td>L₁ x M₂ (Dry zone)</td>
<td>56.46 c</td>
</tr>
<tr>
<td>3</td>
<td>L₁ x M₃ (Dry zone)</td>
<td>52.35 c</td>
</tr>
<tr>
<td>4</td>
<td>L₁ x M₄ (Dry zone)</td>
<td>47.48 cd</td>
</tr>
<tr>
<td>5</td>
<td>L₁ x M₅ (Dry zone)</td>
<td>40.78 d</td>
</tr>
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<td>6</td>
<td>L₁ x M₆ (Dry zone)</td>
<td>36.77 d</td>
</tr>
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<td>7</td>
<td>L₂ x M₁ (Moist zone)</td>
<td>122.50 b</td>
</tr>
<tr>
<td>8</td>
<td>L₂ x M₂ (Moist zone)</td>
<td>129.43 ab</td>
</tr>
<tr>
<td>9</td>
<td>L₂ x M₃ (Moist zone)</td>
<td>132.73 ab</td>
</tr>
<tr>
<td>10</td>
<td>L₂ x M₄ (Moist zone)</td>
<td>136.15 a</td>
</tr>
<tr>
<td>11</td>
<td>L₂ x M₅ (Moist zone)</td>
<td>124.01 b</td>
</tr>
<tr>
<td>12</td>
<td>L₂ x M₆ (Moist zone)</td>
<td>129.55 ab</td>
</tr>
<tr>
<td></td>
<td>Standard error</td>
<td>11.50</td>
</tr>
</tbody>
</table>

Means in each column followed by different letters are significantly different (Duncan 0.05).
Fig. 1—Trends of reducing sugars over time in the three varieties studied in the dry zone.

Table 5—Eigenvectors, eigenvalues and principal components of variables and individuals studied.

<table>
<thead>
<tr>
<th>Parameters and variables</th>
<th>Components</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<tr>
<td>Eigenvalues</td>
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</tr>
<tr>
<td>Percentages</td>
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</tr>
<tr>
<td>Cumulative values</td>
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<tr>
<td>Location (L)</td>
<td>– 0.911</td>
</tr>
<tr>
<td>Variety (B)</td>
<td>– 0.097</td>
</tr>
<tr>
<td>Harvest (C)</td>
<td>0.147</td>
</tr>
<tr>
<td>Replicates (REP)</td>
<td>0.032</td>
</tr>
<tr>
<td>Cane yield (REN)</td>
<td>– 0.949</td>
</tr>
<tr>
<td>Stalk population (NT)</td>
<td>– 0.748</td>
</tr>
<tr>
<td>Stalk length (AT)</td>
<td>– 0.934</td>
</tr>
<tr>
<td>Stalk diameter (DIA)</td>
<td>– 0.835</td>
</tr>
<tr>
<td>Brix</td>
<td>– 0.669</td>
</tr>
<tr>
<td>Fibre (FIB)</td>
<td>0.751</td>
</tr>
<tr>
<td>Moisture (HUM)</td>
<td>– 0.249</td>
</tr>
<tr>
<td>Purity (PUR)</td>
<td>– 0.234</td>
</tr>
<tr>
<td>Reducing sugars (RED)</td>
<td>0.654</td>
</tr>
<tr>
<td>Sucrose (PLS)</td>
<td>– 0.687</td>
</tr>
<tr>
<td>Theoretical sugar/ha (RAT)</td>
<td>– 0.974</td>
</tr>
</tbody>
</table>
Fig. 2—Correlation circle, with representation of the 15 considered variables, according to their importance in the first and second components.

Fig. 3—Behaviour of individuals in the first and second components (in agreement with the importance of variables: location and harvest timing, in both components).
Conclusions

By assessing the location by month of harvest interactions, it is noteworthy that in the dry zone, cane yield was highest early in the season in December, January and February, while yields declined from March. In contrast in the moist zone, the harvest season began with a trend of low cane yields in December and January, and reached a maximum in February and March, and again declined during April and May. This clearly demonstrates the need to take into consideration the characteristics of these locations in order to optimise harvest scheduling.

Reducing sugars presented different trends over time in each variety. In the dry zone, CP 72–2086 exhibited low values (0.297%) early in the harvest season which began to increase significantly in the month of March (0.883%), maintaining these high values until the end of the harvest season in May (1.407%).

Mex 69–290 recorded high values in the month of December (0.617%), which decreased in January (0.288%), February (0.240%) and March (0.507%), and increased again in April and May, with values of 0.797% and 0.873%, respectively.

Mex 79–431 maintained low values from December to March (of 0.470% and 0.500%) with a trend to increase from the month of April (1.003%). These results suggest that variety CP72-2086 should be harvested at the beginning of the harvest season and finalised before March, variety Mex 69-290 should be harvested preferably during the months of January, February and March, while variety Mex 79-431 has best harvest timing in February and March.

The principal components analysis showed important effects of locations on cane and sugar yields and time of harvest, the influence of the environment on varietal yields, and verified the dependence of cane yield on its components stalk population, length and diameter. Negative correlations between yield component variables and moisture, reducing sugars and fibre were also found. The main components analyses demonstrate the total dependence of varietal performance on the conditions of locations and on their harvest management.

REFERENCES


EFFETS DU SITE ET DE LA PÉRIODE DE RECOLTE SUR LES RENDEMENTS DES TROIS PRINCIPALES VARIETES CULTIVEES AU MEXIQUE

Par

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MOTS-CLÉS: Canne à Sucre, Planification de la Coupe.

Résumé

EFECTO DE LA LOCALIDAD Y EL MOMENTO DE COSECHA EN LAS TRES PRINCIPALES VARIEDADES DE CAÑA DE AZÚCAR EN MÉXICO

Por

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PALABRAS CLAVES: Caña de Azúcar, Momento de Cosecha.

Resumen

En México se cultivan con caña de azúcar más de 650 000 hectáreas que tributan las 46.5 millones de toneladas producidas, como promedio de los últimos tres años, a 57 ingenios azucareros, distribuidos a lo largo de la costa del océano pacífico, una franja transversal sobre el paralelo 19 y las costas del golfo de México, los cuales presentan un rendimiento de fábrica de 11.43 como máximo en la mejor zafra; en esta diversidad de clima y suelo, se cultivan mas de 20 variedades, pero el 65% aproximadamente de la superficie está plantada con las variedades: Mex 69-290, CP 72-2086 y Mex 79-431. Con el fin de conocer con precisión el efecto de la edad y la época de cosecha de estas variedades para una óptima programación de su cosecha, se plantaron 2 experimentos, con las tres variedades mencionadas, en dos localidades altamente contrastantes en clima y suelo, del principal macizo cañero del país, los cuales se cosecharon en seis momentos del periodo de la zafra Diciembre/2004 a Mayo/2005. En la zona seca el rendimiento de campo fue mayor a inicios de zafra, en diciembre, enero y febrero, y a partir del mes de marzo se inició un descenso, mientras en la zona húmeda se inició la cosecha con una tendencia de rendimiento bajos en diciembre y enero, que alcanzaron su máximo en febrero y marzo, para declinar durante abril y mayo. Los azúcares reductores presentan un comportamiento específico para cada variedad: En la zona seca, la CP 72-2086 inició cosecha con valores bajos, que se incrementaron significativamente en marzo, manteniéndose altos hasta el final de la cosecha en mayo; la Mex 69-290 inició la cosecha con valores altos en diciembre, que disminuyó durante enero, febrero y marzo, para volver a incrementarse en abril y mayo; y la Mex 79-431 de diciembre a marzo mantienen valores bajos, con una tendencia a incrementarse a partir de abril. El análisis de componentes principales demostró el efecto importante de las localidades en la producción de caña y azúcar y el momento de cosecha, y la dependencia del efecto ambiental de las variedades, y reafirmó la dependencia del rendimiento de campo de sus componentes población, altura y diámetro. También se encontraron correlaciones negativas o inversas entre las variables del rendimiento agrícola con la humedad, la fibra y los azúcares reductores.
PLENE, AN INNOVATIVE APPROACH FOR SUGARCANE PLANTING IN BRAZIL

By

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KEYWORDS: Cane Stalk, One-Budded Cane Setts, Setts Treatments.

Abstract
PLENE™ concept is an evolutionary way of planting sugarcane to replace the current high cost path requiring heavy equipment and intensive labour. With Plene™, Syngenta developed a methodology for producing sugarcane one-budded setts treated with proprietary crop protection and coatings that allows germination, crop stand and vigour. This protocol, associated with an industrial cutting and stalk treatment technologies and a lighter planting machine, provides a dramatic improvement in planting operations, reducing the amount of seed cane from 18 t of stalks to 1.5 t of Plene™ per hectare. This technology has the potential to simplify the planting process and represents a good strategy for sustainable sugarcane production. This paper summarises five field trials carried out to evaluate the performance of Plene™ sugarcane technology in São Paulo State, Brazil. Results have shown that the ideal number of buds per linear metre is 8 when a 1.5 m space between rows is adopted. Application of Plene slurry just after the cutting process increased the shelf life time from 2 to 7 days using 70% buds germination as a reference. Emergence trial results showed the importance of crop protection for the Plene™ technology and, at 48 days after planting assessment, Plene™ plots reached 72% emergence compared to 20% in untreated plots. As a conclusion, the combination of crop protection technologies and polymers in Plene™ is able to maintain the viability of the buds before planting and assures ideal germination and crop stand after planting, thus showing this to be an excellent technology for modern sugarcane planting.

Introduction
The current agronomic technology and industrialisation of sugarcane, associated with tradition and infrastructure, are factors that limit the production in Brazil and, to reach ambitious targets in the near future, an expansion of planted area is needed. Research and new technologies are important to ensure progress in yield, productivity and cost reduction, and the Plene™ concept is being developed in this context.

This Syngenta technology consists of production of healthy cane setts, with one bud and 4 cm long, treated with proprietary crop protection and planted with a 'light' planter (similar to a grain planter). This innovative technology for planting is appropriate for renovation or expansion of areas due to less impact from mechanical operations, and is feasible even under minimum tillage.

The possible combination of planting operations and crop management such as insect, fungus and nematode control provides a lower cost, higher efficacy and efficient logistics.

In the past, and even nowadays, several research projects have been carried out to modernise the planting process. Clements (1940) evaluated the effect of different sizes of stalks and number of buds (1 to 5 buds) and found that smaller sizes and fewer buds were the best; however, rot disease
development was higher due to the larger exposed area of the cut faces. Ricci Junior et al. (2009), working with shorter sugarcane stalks (30 cm) and two buds without fungicide, reported that sprouting and tillering were significantly damaged due to pineapple disease (*Ceratocystis paradoxa*).

Casagrande and Vasconcelos (2008) reported that there is a sprouting gradient due to age differences between the buds, from the top (younger) to bottom (older). Alvarez (1975) and Pange et al. (1962) reported that old stalks are unsuitable for planting, the ideal is seven to nine months stalk age, and the top third germinates better than the middle and bottom third.

Valdez Manzano (1976), Rincones (1973), Escobar (1968) and Martín (1951) found that for seed cane without fungicide treatment, the interval between cutting and planting should be the lowest possible, no more than 4–7 days.

This work aimed at studying the best small segment density for planting, sprouting of buds originating from different segments (top, middle and base) of the stalks, planting position of these segments in the ground, and shelf life of the buds produced with the Plene™ technology.

**Materials and methods**

All the trials were conducted at Holambra Field Station (22°38′S, 47°05′W) in Holambra, SP, Brazil, between December 2007 and June 2009. Anova and ‘t’ test were applied for statistical analysis of the five trials.

**Planting density (Trial No. 1)**

Small segments (4 cm long) with one bud were taken off from the middle and top of the cane stalks of the cultivar RB 86-7515. They were treated through industrial proprietary Syngenta crop protection (Plene™).

The segments were planted in furrows 30 cm deep, fertilised in accordance with requirement and covered with 5–8 cm of soil. Plot size was 4 rows of 5 m in length and the experimental design adopted was randomised complete blocks (RCB) and factorial scheme (3 × 2); three density treatments, namely four, eight and 12 segments with one bud per linear metre and two chemical treatments: 1) treated one-bud sett and 2) non-treated one-bud sett. Each treatment was replicated four times. Evaluations of germination (% emergence), height (up to dewlap), stalk diameter (4th knot), cane yield and sugar content were made to derive the optimum density of small segments.

**Segment and age of bud (Trial No. 2)**

Small segments originating from top, middle and bottom of mother stalks were removed from nine and 12 month age cane stalks. They were treated with the industrial proprietary treatment of Plene™. Planting was made in furrow 30 cm deep, fertilised according to requirement and covered with 5–8 cm of soil.

The experimental design adopted was a RCB and factorial scheme (3 × 2); three segment treatments, namely bottom, middle and top and two ages, namely 12 and 9 months. Each treatment was replicated four times; plot-size was 4 rows of 5 m long.

Measurements and data recording included evaluations of emergence, stalk height and diameter, cane and sugar yield.

**Segment size (Trial No. 3)**

Small segments of different lengths (4, 6, 8, 10 and 12 cm) were taken from top and middle of mother stalks. They were treated through industrial proprietary treatment before being planted in furrows 30 cm deep, fertilised at recommended rates and covered with 5–8 cm of soil.

The experimental design adopted was a RCB with 4 replications with plot size of 4 rows of 5 m long. Evaluations of emergence, stalk height, stalk diameter, cane yield and kg sugar/ha were the parameters measured.
Bud planting angle (Trial No. 4)

Small segments were produced in a similar way to those in Trial No. 1 (density of planting trial). They were treated through industrial proprietary crop protection (Plene™) and the management to planting was the same except that eight one-bud setts were planted per linear metre for all the plots.

The experimental design adopted was RCB with four repetitions; plot size adopted was 4 rows of 5 m long. To study the best planting bud position of small segments in the furrow, they were planted at different angles with regard to the soil surface as illustrated in Figure 1. The four treatments had segments placed at: 1) 0º, 2) 90º, 3) 180º, 4) 270º.

![Figure 1—Bud positions at different angles to the soil surface.](image)

Shelf life (Trial No. 5)

A pot trial was carried out in the greenhouse where eight small segments, cut and chemically treated immediately after cutting in comparison to those treated only at planting time, were planted in pots of 20 L.

Periods of storage of small segments were 0, 3, 5, 7, 10 and 12 days. The experimental design adopted was a completely randomised design with a factorial scheme of 2 x 6 (two treatment times and 6 periods of storage); all treatments replicated four times. Germination (% emergence) at 45 days after planting was evaluated.

Results and discussion

Planting density (Trial No. 1)

Emergence of one-budded setts, height and diameter of stalks, yield and sugar/ha were evaluated and showed that bud setts treated with Syngenta products were clearly superior to untreated budded setts, and it was significant for one density at least. Height was the parameter that showed superiority of treated bud setts for the three densities evaluated.

In general, eight and 12 buds/linear metre were superior to four, mainly for yield and sugar/ha. Summarising, the results showed that 8 buds per linear metre, after being treated chemically, showed the ideal density for Plene™ technology for the variety RB86 7515 and the necessity to treat the small segments with chemicals to improve the emergence, height and yield.

These data are in agreement with Ricci Jr et al. (2009) and Clements (1940) where they found the importance of crop protection when the stalk length is smaller than that of conventional cane setts (4 cm and one-bud sett versus 40 cm and 3 buds) (Tables 1, 2, 3 and 4).
### Table 1—Emergence percentage of Plene™ at 22 and 36 DAP planted in different densities, in comparison with untreated bud setts. Holambra, SP.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>% Emergence–22 DAP</th>
<th>% Emergence–36 DAP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4/ metre 8/ metre 12/ metre</td>
<td>4/ metre 8/ metre 12/ metre</td>
</tr>
<tr>
<td>Untreated</td>
<td>15.0 aA 14.7 aA 14.6 aA</td>
<td>31.3 aA 40.6 aA 29.8 aA</td>
</tr>
<tr>
<td>Treated†</td>
<td>26.9 aA 28.4 bA 27.3 aA</td>
<td>60.6 bA 50.3 aA 51.9 bA</td>
</tr>
<tr>
<td>Standard error (s.e.)</td>
<td>5.1935</td>
<td>6.6802</td>
</tr>
</tbody>
</table>

† Industrial proprietary treatment  
‡ DAP: days after planting  
Means within columns followed by the same small letter not significantly different by ‘t’ test. Means within rows followed by the same capital letter not significantly different by ‘t’ test. Both at 10% probability.

### Table 2—Height and diameter of Plene™ at 192 DAP planted in different densities, in comparison with untreated bud setts. Holambra, SP, Brazil, 2008/09.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Height (cm)–192 DAP</th>
<th>Diameter (mm)–192 DAP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4/ metre 8/ metre 12/ metre</td>
<td>4/ metre 8/ metre 12/ metre</td>
</tr>
<tr>
<td>Untreated</td>
<td>150.3 aA 158.3 aA 176.5 bA</td>
<td>28.9 aA 28.8 aA 28.8 aA</td>
</tr>
<tr>
<td>Treated†</td>
<td>174.3 bA 172.3 bA 190.8 bB</td>
<td>30.3 bA 29.6 aA 30.4 aA</td>
</tr>
<tr>
<td>Standard error (s.e.)</td>
<td>4.2247</td>
<td>0.5517</td>
</tr>
</tbody>
</table>

† Industrial proprietary treatment  
‡ DAP: days after planting  
Means within columns followed by the same small letter not significantly different by ‘t’ test. Means within rows followed by the same capital letter not significantly different by ‘t’ test. Both at 10% probability.

### Table 3—Yield of Plene™ at 552 DAP planted in different densities, in comparison with untreated bud setts. Holambra, SP, Brazil, 2008/09.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Yield (t/ha)–552 DAP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4/ metre 8/ metre 12/ metre</td>
</tr>
<tr>
<td>Untreated</td>
<td>144.7 aA 167.2 aA 148.9 aA</td>
</tr>
<tr>
<td>Treated†</td>
<td>155.8 aA 214.4 bB 188.4 abA</td>
</tr>
<tr>
<td>Standard error (s.e.)</td>
<td>17.6932</td>
</tr>
</tbody>
</table>

† Industrial proprietary treatment  
‡ DAP: days after planting  
Means within columns followed by the same small letter not significantly different by ‘t’ test. Means within rows followed by the same capital letter not significantly different by ‘t’ test. Both at 10% probability.

### Table 4—ATR and Sugar at 552 DAP when Plene™ is planted in different densities, in comparison with untreated bud setts. Holambra, SP, Brazil, 2008/09.

<table>
<thead>
<tr>
<th>Treatment†</th>
<th>ATR (kg/t)–552 DAP</th>
<th>Sugar (kg/ha)–552 DAP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bottom Middle Top</td>
<td>Bottom Middle Top</td>
</tr>
<tr>
<td>Untreated</td>
<td>132.3 aA 129.4 aA 125.9 aA</td>
<td>14,284 aA 18,499 aA 14,206 aA</td>
</tr>
<tr>
<td>Treated†</td>
<td>128.3 aA 127.2 aA 128.4 aA</td>
<td>17,137 aA 21,479 aA 20,437 bA</td>
</tr>
<tr>
<td>Standard error (s.e.)</td>
<td>4.6507</td>
<td>4,5013</td>
</tr>
</tbody>
</table>

† † Industrial proprietary treatment  
‡ DAP: days after planting  
Means within columns followed by the same small letter not significantly different by ‘t’ test. Means within rows followed by the same capital letter not significantly different by ‘t’ test. Both at 10% probability.
Segment/age (Trial No. 2)

Segments of nine month age were shown to be significantly superior to 12 months for all different segments (top, middle and bottom) and all parameters evaluated, except for diameter where 12 month age for all different segments were superior to nine months, as expected because of low stand (Tables 5, 6, 7 and 8). Casagrande and Vasconcelos (2008) reported that there is a sprouting gradient due to age differences between the bud age, from the top (younger) to bottom (older) and Alvarez (1975) and Pange et al. (1962) showed that old stalks are unsuitable for planting, the ideal is seven to nine month stalk age, and the top third germinates better than the middle and bottom third.

Table 5—Emergence of one-bud setts (4 cm) taken from bottom, middle and top segment of the mother stalks at nine and 12 month age. Holambra, SP, Brazil, 2008/09.

<table>
<thead>
<tr>
<th>Treatments¹</th>
<th>% Emergence – 23 DAP²</th>
<th>% Emergence – 37 DAP²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bottom</td>
<td>Middle</td>
</tr>
<tr>
<td>12 month age</td>
<td>0.94 aA</td>
<td>4.69 aA</td>
</tr>
<tr>
<td>9 month age</td>
<td>54.69 bA</td>
<td>55.94 bA</td>
</tr>
<tr>
<td>Standard error (s.e.)</td>
<td>3.3379</td>
<td>2.3641</td>
</tr>
</tbody>
</table>

¹ Industrial proprietary treatment
² DAP: days after planting

Means within columns followed by the same small letter not significantly different by ‘t’ test. Means within rows followed by the same capital letter not significantly different by ‘t’ test. Both at 10% probability.

Table 6—Height and diameter of one-bud setts taken from bottom, middle and top segment of the mother stalks at nine and 12 month age. Holambra, SP, Brazil, 2008/09.

<table>
<thead>
<tr>
<th>Treatment¹</th>
<th>Height (cm)–200 DAP²</th>
<th>Diameter (mm)–200 DAP²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bottom</td>
<td>Middle</td>
</tr>
<tr>
<td>12 month age</td>
<td>67.13 aA</td>
<td>77.12 aA</td>
</tr>
<tr>
<td>9 month age</td>
<td>137.85 bA</td>
<td>129.18 bA</td>
</tr>
<tr>
<td>Standard error (s.e.)</td>
<td>6.9479</td>
<td>0.8210</td>
</tr>
</tbody>
</table>

¹ Industrial proprietary treatment
² DAP: days after planting

Means within columns followed by the same small letter not significantly different by ‘t’ test. Means within rows followed by the same capital letter not significantly different by ‘t’ test. Both at 10% probability.

Table 7—Yield of one-bud setts taken from bottom, middle and top segment of the mother stalks at nine and 12 month age. Holambra, SP, Brazil, 2008/09.

<table>
<thead>
<tr>
<th>Treatment¹</th>
<th>Yield (t/ha)–514 DAP²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bottom</td>
</tr>
<tr>
<td>12 month age</td>
<td>130.39 aAB</td>
</tr>
<tr>
<td>9 month age</td>
<td>169.81 bA</td>
</tr>
<tr>
<td>Standard error (s.e.)</td>
<td>9.9696</td>
</tr>
</tbody>
</table>

¹ Industrial proprietary treatment
² DAP: days after planting

Means within columns followed by the same small letter not significantly different by ‘t’ test. Means within rows followed by the same capital letter not significantly different by ‘t’ test. Both at 10% probability.
Table 8—ATR (kg/t) and Sugar (kg/ha) of one-bud setts taken from bottom, middle and top segment of the mother stalks at nine and 12 month age. Holambra, SP, Brazil, 2008/09.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>ATR (kg/t)–514 DAP</th>
<th>Sugar (kg/ha)–514 DAP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bottom</td>
<td>Middle</td>
</tr>
<tr>
<td>12 month age</td>
<td>126.03 aB</td>
<td>116.93 aA</td>
</tr>
<tr>
<td>9 month age</td>
<td>116.21 bA</td>
<td>129.94 bB</td>
</tr>
<tr>
<td>Standard error (s.e.)</td>
<td>2.6049</td>
<td></td>
</tr>
</tbody>
</table>

1 1 Industrial proprietary treatment
2 DAP: days after planting
Means within columns followed by the same small letter not significantly different by ‘t’ test. Means within rows followed by the same capital letter not significantly different by ‘t’ test. Both at 10% probability.

Segment size (Trial No. 3)

Evaluations of germination (% emergence) at 24 and 35 DAP, height and diameter at 207 DAP showed that there was no difference between the segment sizes (4, 6, 8, 10 and 12 cm) tested. However, the best cane yield was obtained with segments of 12 cm and the best kg sugar/ha was with 10 cm long setts. Clements (1940), in his studies about sprouting, found working with different sizes and number of buds (1 to 5 buds per stalk), the best size was with the smaller length of stalk and fewer buds (Table 9).

Table 9—Effect of different size of segments with one bud for planting (4, 6, 8, 10 and 12 cm). Holambra, SP, Brazil, 2008/09.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>% emergence</th>
<th>Height (cm)</th>
<th>Diameter (mm)</th>
<th>t/ha</th>
<th>ATR kg sugar/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plene Size</td>
<td>24 DAP 1</td>
<td>35 DAP 2</td>
<td>207 DAP 3</td>
<td>514 DAP 4</td>
<td></td>
</tr>
<tr>
<td>1) 4 cm</td>
<td>36.8</td>
<td>57.8</td>
<td>104.5</td>
<td>27.6</td>
<td>162.8 ab</td>
</tr>
<tr>
<td>2) 6 cm</td>
<td>43.3</td>
<td>56.0</td>
<td>103.9</td>
<td>29.3</td>
<td>153.5 a</td>
</tr>
<tr>
<td>3) 8 cm</td>
<td>42.0</td>
<td>52.8</td>
<td>108.1</td>
<td>30.9</td>
<td>171.2 ab</td>
</tr>
<tr>
<td>4) 10 cm</td>
<td>42.0</td>
<td>58.5</td>
<td>123.5</td>
<td>27.9</td>
<td>195.4 b</td>
</tr>
<tr>
<td>5) 12 cm</td>
<td>43.3</td>
<td>62.3</td>
<td>109.5</td>
<td>28.1</td>
<td>177.6 ab</td>
</tr>
<tr>
<td>Standard error (s.e.)</td>
<td>3.2641</td>
<td>2.8740</td>
<td>4.2521</td>
<td>0.5109</td>
<td>14.5787</td>
</tr>
</tbody>
</table>

1 DAP: days after planting
2 Treated: industrial proprietary treatment

Bud planting angle (Trial No. 4)

Germination (% emergence) at 25 and 36 DAP was slower with the cane setts/segments placed at 180º and 270º. This may be due to these bud positions requiring more energy to emerge from the soil.

These slower developments resulted in lower stalk height at 125 DAP. Angles of 0º and 90º were the best positions; however, they were similar to the randomised position. Stalk height at 125 DAP confirmed that angles of 0º and 90º were the best positions. Diameter at 125 DAP, yield and kg sugar/ha (550 DAP) of all angles of bud planting, including the randomised position, showed no significant difference between the treatments.

These data are interesting because they show that, if the one-budded setts are treated with Plene’s products, it is not necessary to plant the setts in a determined position. Nickell (1977) found similar results when studying depth and angle of planting (Table 10).
Table 10—One-budded cane setts planted with different bud position in soil (0º, 90º, 180º, 270º and randomised). Holambra, SP, Brazil, 2008/09.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>% emergence</th>
<th>Height (cm)</th>
<th>Diameter (mm)</th>
<th>t/ha</th>
<th>ATR</th>
<th>kg sugar/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25 DAP1</td>
<td>36 DAP</td>
<td>125 DAP</td>
<td>550 DAP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1) 0º</td>
<td>50.6 b 66.9 b</td>
<td>54.6 b 24.9</td>
<td>165.5 138.2 21.610</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2) 90º</td>
<td>45.6 b 65.0 b</td>
<td>55.0 b 26.6</td>
<td>155.9 138.5 19.350</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3) 180º</td>
<td>30.0 a 59.7 ab</td>
<td>48.4 ab 26.2</td>
<td>162.0 137.0 19.820</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4) 270º</td>
<td>24.4 a 53.1 a</td>
<td>45.2 a 25.6</td>
<td>161.5 136.3 19.390</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5) Randomised</td>
<td>44.4 b 68.1 b</td>
<td>46.6 a 25.1</td>
<td>165.5 134.4 19.580</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard error (s.e.)</td>
<td>4.6505</td>
<td>3.2914</td>
<td>2.8750</td>
<td>0.7868</td>
<td>8.2368</td>
<td>3.4688</td>
</tr>
</tbody>
</table>

1 DAP: days after planting
2 Planting angle means the angle formed in regarding to ground.

Shelf life (Trial No. 5)

Small segments treated immediately after cutting, assuming a threshold of 70% emergence, storage at room temperature, the evaluation of germination (% emergence) at 45 days after planting showed that shelf life for one-budded setts treated with proprietary crop protection is seven to ten days. However, shelf life of small segments cut and left untreated until planting time, showed a drastic decline after two days of storage.

In the latter case, a high infection level of saprophyte fungi and other organisms was observed that probably killed the majority of buds in five days (Table 11 and Figure 2). Other researchers (Valdez Manzano, 1976; Rincones, 1973; Escobar, 1968; and Martin, 1951) found similar results and reported that, for seedlings without fungicide treatment, the interval between cutting and planting should be the lowest possible, no more than 4–7 days.

Table 11—Shelf life of segments chemically treated immediately after cutting in comparison with segments treated only at planting time. Holambra, SP, Brazil, 2008.

<table>
<thead>
<tr>
<th>Treatment time</th>
<th>Days of storage Plene</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Treatment immediately after cutting</td>
<td>701 aA</td>
</tr>
<tr>
<td>Treatment before planting</td>
<td>70 aA</td>
</tr>
<tr>
<td>Standard error (s.e.)</td>
<td>14.89</td>
</tr>
</tbody>
</table>

1 Germination percentage
The Plene™ concept is being developed by Syngenta Crop Protection with contribution from Brazilian mills to make a major breakthrough in cane planting. Several aspects covered in this paper show the viability of this technology to revolutionise sugarcane planting, with a simplified process, efficient logistics and sustainable cane production.

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PLENE, UN CONCEPT INOVANT DE PLANTATION DE CANNE A SUCRE AU BRESIL

Par

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MOTS CLEFS: Tige de Cane, Bouture, Traitement de Boutures.

Résumé

LE CONCEPT Plene™ est novateur, il a remplacé la méthode onéreuse habituelle de plantation qui nécessita un degré élevé de mécanisation et une main d’œuvre abondante. Grâce à Plene™, Syngenta a développé une méthode évolutée pour produire des boutures traitées d’un œil possédant des caractéristiques de résistance et de vigueur favorisant une bonne germination et levée. Cette méthode associe la préparation et le traitement industriel des boutures à une plantation espacée, elle améliore l’efficience des opérations de plantation en réduisant la quantité de boutures utilisées de 18 t à 1.5 t par hectare. La technologie Plene™ a la capacité de simplifier la plantation et contribue à une production de canne à sucre durable. Cet article résume cinq essais conduits pour évaluer les performances de la technique Plene™ et réalisés dans l’état de São Paulo au Brésil. Les résultats démontrent qu’avec un espacement de 1.5 m d’espacement entre deux lignes, la densité de 8 boutures est optimum. L’application de la pâte Plene au moment de la coupe des boutures allonge leur durée de vie de 2 à 7 jours dans 70% des cas. Les essais sur la levée montrent l’efficacité de la protection par la technique PleneTM, avec un taux de germination de 72% avec traitement contre 20% sans. En conclusion, la combinaison de la protection offerte par la technique et l’utilisation de polymères PleneTM permet de conserver les boutures en vie avant plantation et d’assurer la germination et la survie des plants, tout ceci pouvant représenter une excellente technique de plantation moderne de canne à sucre.
PLENE, UN ENFOQUE INNOVADOR PARA SIEMBRA DE CAÑA DE AZÚCAR EN BRASIL

Por

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PALABRAS CLAVE: Tallo de Caña, Semilla con una Yema, Tratamiento de Semilla.

Resumen

El concepto Plene™ es una forma evolutiva en la siembra de caña de azúcar para sustituir la práctica actual que requiere maquinaria pesada y mano de obra intensiva. Con Plene™, Syngenta desarrolló una metodología para trozos de caña con una yema tratados con recubrimientos protectores de su propiedad que permiten buenas germinación, densidad y vigor. Este protocolo, asociado con tecnologías industriales de corte y tratamiento de las estacas y una máquina sembradora liviana, ofrece una notable mejora en las operaciones de siembra, reduciendo la cantidad de semilla de caña de 18 t a 1.5 t por hectárea con Plene™. Esta tecnología tiene el potencial de simplificar el proceso de siembra y representa una buena estrategia para una producción sostenible de caña de azúcar. Este documento resume cinco estudios de campo llevados a cabo en el estado São Paulo, Brasil para evaluar el desempeño de la tecnología de Plene™. Los resultados han demostrado que el número ideal de yemas por metro lineal es de 8 cuando se adopta un espaciamiento de 1.5 m entre surcos. La aplicación de Plene justo después del proceso de corte aumenta el tiempo de vida útil de 2 a 7 días tomando el 70% de germinación de las yemas como referencia. La emergencia de las yemas en los ensayos puso de manifiesto la importancia de la protección fitosanitaria de la tecnología Plene™ y, a los 48 días al realizar la evaluación de la siembra, las parcelas con Plene™ alcanzaron el 72% de emergencia, frente al 20% en las parcelas no tratadas. Como conclusión, la combinación en Plene™ de las tecnologías de protección de cultivos y polímeros es capaz de mantener la viabilidad de las yemas antes de la siembra y asegura una germinación y densidad de tallos ideales después de la siembra, lo que demuestra que se trata de una excelente tecnología para la siembra moderna de la caña de azúcar.
NITROGEN IN SUGARCANE DERIVED FROM FERTILISER

By


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KEYWORDS: Green-cane, $^{15}$N Labelled Urea, Sugarcane Trash, Saccharum spp.

Abstract

NITROGEN fertilisation in the sugarcane crop is a universal practice used to reach sustainable levels of productivity, both in the plant cane and especially in ratoon cycle. However, when evaluating N in the plant derived from fertiliser ($^{15}$N) at crop harvest, one sees that this contribution is in the order of 20% of the total N, which gives rise to questions regarding the efficiency of this fertilisation. Therefore, field experiments were undertaken at two locations with sugarcane mechanically harvested and without burning of the sugarcane in the State of São Paulo, Brazil. Nitrogen fertilisation of both the plant cane (rates of 40, 80 and 120 kg/ha of N as urea) and the first ratoon (rates of 50 and 100 kg/ha of N as ammonium sulfate) was labelled on the stable isotope of $^{15}$N. It was observed that the N from nitrogen fertilisation represented up to 40% of the total N of the plant cane in the initial stages of its growth, decreasing in the stages of pre-maturity and at maturity to levels in the order of 10% at harvest. In the ratoon crop, participation of N fertiliser on crop nutrition was more effective, constituting up to 70% of total N in the initial stages of development, especially at greater rates of N, decreasing through the cycle of the first ratoon. Nevertheless, it stands out that, throughout the growth of the ratoon, the contribution of N fertiliser was greater than that for the plant cane, to the order of 30% of the total N of the plant. This confirms that N fertilisation in the ratoon crop, with little or no soil tillage, together with the maintenance of crop residues on the soil surface, is one of the most important sources of N for the crop.

Introduction

In studies with sugarcane, one of the most controversial and polemical matters is in respect to nitrogen fertilisation at planting (plant cane), considering that many studies have shown sugarcane has little response to this practice (Trivelin, 2000; Franco, 2008). One sees in the literature a lack of response in most experiments with the plant crop when the sugarcane is burnt prior to harvest (Trivelin, 2000). For the regrowth, with burnt cane, most of the experiments showed a response (Trivelin, 2000). Many explanations have been given, such as biological fixation of atmospheric N, losses through leaching of N fertiliser, the vigour of the root system of the plant cane compared to that of the ratoons, the climatic conditions, the improvement in soil fertility associated with liming, mechanical soil preparation and the incorporation of residues from the previous crop (Orlando Filho et al., 1999; Urquiaga et al., 1992). According to the review of Salcedo and Sampaio (1984), in ratoon cane, response is more frequent due to a smaller quantity of mineral N accumulated in the soil profile at the beginning of the ratoon growth cycle compared to that of the plant cane, less mineralisation of N from the soil due to reduced soil tillage, and less efficiency of the ratoon root system in uptake of fertiliser-N.
In this context, for the purpose of understanding in a more detailed way the N cycle in the soil-plant system and its effect on the development and productivity of sugarcane in Brazil, studies with the use of the isotope tracer method for nitrogen ($^{15}$N) were begun in 1983 at the Center for Nuclear Energy in Agriculture, at the University of São Paulo. One of the evaluations that may be undertaken with the use of the isotope tracer technique is an estimate of the percentage of nitrogen in the plant derived from fertiliser (%NDFF) and the efficiency in the use of N fertiliser by the crops. In the sugarcane crop, this technique may be used during its growth cycle. The hypothesis in these experiments with sugarcane is that the F+3 of the plant represents the abundance of $^{15}$N in the above ground part of the crop (shoot of the crop) and in view of this, the isotopic abundance is used to estimate the NDFF of the above ground part (Takahashi, 1967; Sampaio et al., 1984; Trivelin, 2000).

Recently, due to the small contribution, around 20% or less, of the N fertiliser in the total N accumulated in the above ground part of the plants, at the harvest of the sugarcane fields (Sampaio et al., 1984; Trivelin et al., 1995; Trivelin, 2000; Gava et al., 2001; Franco, 2008), the experts of sugarcane management began to question the efficacy of nitrogen fertilisation in the sugarcane producing regions of the Central-South of Brazil. In this context, with the objective of better understanding of the participation of N fertiliser throughout the growth cycles of the plant cane and the first crop regrowth, two field experiments were developed with the objective of evaluating the contribution of $^{15}$N-fertiliser (urea in the plant cane and ammonium sulfate in the first ratoon) in the total nitrogen accumulated in the above ground part of the sugarcane during both growth cycles.

**Material and methods**

**Location, trial design and $^{15}$N labelled fertiliser**

The experiments were developed in two sugarcane producing areas located in the State of São Paulo, Brazil. The first belongs to the São Luiz Sugar Mill (USL), in the Pirassununga county (Latitude 21º55’54’’S, Longitude 47º10’54’’W). This area had been cultivated with sugarcane since 1977. The altitude is 650 m and the climate is Aw (Tropical Savanna, in the Köppen classification). The area presents a slightly rolling slope (< 5%) and the soil is Typic Eutrustox. Planting of the sugarcane occurred from February 21 to 24, 2005. The second area, belonging to the Santa Adélia Sugar Mill (USA) is in the Jaboticabal county (Latitude 21º19.98’S, Longitude 48º19.03’’W), with predominant altitude in the region of 600 m and climate Aw (Tropical Savanna, in the Köppen classification). This area had been cultivated with sugarcane since 1951. The area presents a slightly rolling slope (<5%) and the soil is an Arenic Kandiustults. The experiment was planted from April 4 to 8, 2005. The variety used was SP81-3250, and 17 to 20 buds were planted per metre of row and were covered with soil. In all the plots, at the bottom of the furrow, 120 kg/ha of K$_2$O and 120 kg/ha of P$_2$O$_5$ were applied.

Treatments for the plant cane were three rates of N (40, 80 and 120 kg/ha as urea) applied at the bottom of the planting furrow, plus one control without nitrogen fertiliser. Treatments were distributed in a randomised block design with four replications. The experimental plots consisted of 48 rows of 15 metres in length with a space between rows of 1.5 m. In the inside of each plot (20th row), a microplot was installed, with the dimensions of 2 m in length and 1.5 m width, totalling 3 m$^2$, which received the urea labelled with $^{15}$N (5.04 atoms % of $^{15}$N).

**Harvesting, sampling and statistical analysis**

During the growth cycle of the plant cane, samples were taken to evaluate the accumulation of N in the aboveground biomass of sugarcane. At USL, these evaluations were undertaken on July 7, 2005 (134 days after planting–DAP), October 25, 2005 (244 DAP), December 13, 2005 (293 DAP), February 20, 2006 (358 DAP), April 12, 2006 (413 DAP) and June 6, 2006 (468 DAP), for a total of 6 samplings. In the experiment at USA, sampling occurred on October 11, 2005 (186 DAP), December 9, 2005 (246 DAP), February 8, 2006 (307 DAP), April 5, 2006 (363 DAP) and July 10,
2006 (459 DAP), for a total of 5 samplings. In sampling, collection of the entire above ground part of the plant in 2 metres of the row was made at locations previously drawn by lot. The mass of all the plant material (dry leaves, top and stems) from each plot was obtained directly in the field, by means of weighing on an electronic scale. After weighing, each plant sample was chopped in a forage chopper. The sub-samples were packed in plastic bags and were weighed on an analytic scale, before and after drying in a ventilated laboratory dryer at 65°C (72 hours) for determination of the moisture of the material. The dried sub-samples were ground for the chemical determination of total-N content (g/kg) according to Malavolta et al. (1997).

At the same sampling times of the above ground part of the sugarcane, samples of leaves +3 (F+3) were collected in the microplots that received urea-15N. The F+3 were collected according to the methodology described by Trivelin et al. (1994). In these evaluations, samples of leaves +3 using the Dillewijn system are collected in microplots that received the fertiliser labelled with 15N, for determination of the abundance in atoms % of the isotope, thus allowing the determination of estimates of NDFF (kg/ha); also making use of measurements of N accumulated by the crop, obtained in plants collected in other rows of sugarcane in the same plot (treatment). These samples were dried in forced air circulation laboratory ovens at 65°C and the abundance of 15N (atom % of 15N) in them was determined in a mass spectrometer. With the values of the abundance in atoms % of 15N in the samples of leaf +3 and the accumulated N in the above ground part of sugarcane, it was possible to calculate the NDFF (nitrogen in the above ground part of the plant derived from fertiliser) according to the methodology described by Trivelin et al. (1994).

After the harvest of the plant cane (June 6, 2006 at USL and July 10, 2006 at USA), the plots of the two experiments were split into four subplots that received the treatments: 50, 100 and 150 kg/ha of ammonium sulfate, plus a control without application of nitrogen fertiliser. The application of nitrogen fertiliser was made over the cultural residue (trash) coming from the mechanical harvesting without straw burning, at approximately 20 cm from the row, applying together with this 150 kg/ha of K2O.

Inside the plots of the ratoons that received the rates of 50 and 100 kg/ha of N, microplots were demarcated with dimensions of 2 m length and 1.5 m width (3 m²) which received the ammonium sulfate labelled with 15N (2.31% and 2.97 atoms % of 15N, respectively, in the rates of 100 and 50 kg/ha of N), the application of which followed the same procedure as described for the rest of the plots. The fertilisers were applied on October 8 and on November 1st, 2006, respectively, at USL and USA.

In the cycle of the first ratoon, samples of plant material were undertaken in the two locations. This sampling followed the same procedure adopted for the plant cane, determining the plant dry matter and the accumulated N in the above ground part of the sugarcane in each period.

At the same times of collection of plant material, leaves +3 of plants from the microplots that received the ammonium sulfate labelled with 15N were collected, and the same protocol of collection of the leaves as used in the plant cane was carried out (Trivelin et al., 1994), as well as in determination of the 15N abundances.

The results of total N (kg/ha ) and NDFF (% and kg/ha ) were submitted to ANOVA as plots subdivided in time (rates as main treatment and periods as secondary) and the Tukey test for comparison of the averages within each treatment.

Results and discussion

Plant cane crop cycle

In the two experiments, approximately 180 days after the nitrogen fertilisation at planting (October 2005), the sugarcane had already absorbed practically all the N fertiliser, especially for the doses of 40 and 80 kg/ha of N (Table 1), differently from the total N in the plants, which continued being accumulated with the growth of the crop (Table 2). The accumulation of nitrogen (kg/ha )
increased in a linear way with nitrogen fertilisation in the USL experiment; however, there was no effect at USA. The stalk yield was increased with 40 kg N/ha in the USL site (134 t/ha without N and 142 t/ha with 40 kg N/ha), but in USA there was no response in cane yield to N rates (Franco, 2008). At USL, the increases began to be significant as of October, coinciding with the beginning of the maximum growth stage of the crop (Franco, 2008) when the climatic conditions (temperature, solar luminosity and rainfall) began to be raised.

**Table 1**—Estimate of the nitrogen in the plant derived from fertiliser (NDFF) during the plant cane cycle in the São Luiz and Santa Adélia Sugar Mills experiments (2005/2006 harvest).

<table>
<thead>
<tr>
<th>Rates of N (kg/ha)</th>
<th>July</th>
<th>October</th>
<th>December</th>
<th>February</th>
<th>April</th>
<th>June/July*</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDFF, kg/ha</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>6.13A</td>
<td>8.46A</td>
<td>8.82A</td>
<td>9.23A</td>
<td>7.46A</td>
<td>7.80A</td>
</tr>
<tr>
<td>80</td>
<td>11.89B</td>
<td>20.08AB</td>
<td>21.97A</td>
<td>15.82AB</td>
<td>23.76A</td>
<td>18.58AB</td>
</tr>
<tr>
<td>120</td>
<td>17.10B</td>
<td>23.48B</td>
<td>24.97B</td>
<td>25.28B</td>
<td>36.96A</td>
<td>22.89B</td>
</tr>
<tr>
<td>L.S.D. = 8.0 CV = 28%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 2**—Accumulation of nitrogen in the above ground part of sugarcane plant season in two fields of the State of São Paulo, Brazil.

<table>
<thead>
<tr>
<th>Rates of N (kg/ha)</th>
<th>July</th>
<th>October</th>
<th>December</th>
<th>February</th>
<th>April</th>
<th>June/July*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accumulation of N, kg/ha</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>São Luiz Sugar Mill</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>30 D</td>
<td>66 D</td>
<td>106 BC</td>
<td>122 AB</td>
<td>162 A</td>
<td>132 AB</td>
</tr>
<tr>
<td>40</td>
<td>32 C</td>
<td>91 B</td>
<td>84 B</td>
<td>123 AB</td>
<td>152 A</td>
<td>154 A</td>
</tr>
<tr>
<td>80</td>
<td>43 C</td>
<td>100 B</td>
<td>136 B</td>
<td>142 B</td>
<td>224 A</td>
<td>207 A</td>
</tr>
<tr>
<td>120</td>
<td>39 E</td>
<td>91 D</td>
<td>115 CD</td>
<td>158 BC</td>
<td>254 A</td>
<td>192 B</td>
</tr>
<tr>
<td>R²-L.R.</td>
<td>0.55**</td>
<td>0.23*</td>
<td>0.91***</td>
<td>0.84***</td>
<td>0.77***</td>
<td></td>
</tr>
<tr>
<td>R²-Q.R.</td>
<td>0.99*</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>0.87*</td>
<td></td>
</tr>
<tr>
<td>L.S.D. = 49 C.V. = 19%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Santa Adélia Sugar Mill**

| 0 | 114 C | 111 C | 148 BC | 183 AB | 204 A |
| 40 | 108 B | 118 B | 164 A | 173 A | 184 A |
| 80 | 111 D | 139 CD | 154 BC | 195 AB | 227 A |
| 120 | 113 B | 134 B | 196 A | 181 A | 183 A |
| Average | 111 C | 126 C | 166 B | 183 AB | 199 A |
| L.S. D. = 21 C.V. = 13% |

Equal capital letters in the line do not differ among themselves by the Tukey test at 5% probability. L.S.D.: least significant difference; CV: coefficient of variation; *June/July: June at the São Luiz Sugar Mill and July at the Santa Adélia Sugar Mill.

The quantities of N accumulated by the above ground part of the plant cane (190 kg/ha on average) are much more than the rates of N applied (Table 2).

Consequently, it may be inferred that the majority of N absorbed by the plants originated from other sources; the net mineralisation through soil organic carbon rundown, the mineralisation of crop residues (Ng Kee Kwong *et al.*, 1987), and the biological nitrogen fixation by microorganisms associated with the crop or not (Urquiaga *et al.*, 1992) may be highlighted.

In relation to the results of NDFF (%) and use of the $^{15}$N-urea (kg/ha) by the plant cane, it may be highlighted that in the two experiments, the greatest values of NDFF (%) were obtained in
the first samplings, showing that, in the initial stages of development of the crop, a substantial part of the total N of the plants was derived from the fertiliser, especially in the 120 kg/ha rate of N (Figure 1). This can be related to the soil organic carbon immobilising fertiliser N, creating a direct competition with the crop. In addition, at the end of the plant cane cycle, the N fertiliser represented a small fraction of the total N of the above ground part of the plant, indicating that the sugarcane obtains a significant quantity of N from other sources, as previously cited.

Fig. 1—Nitrogen derived from fertiliser in the total N of the above ground part of sugarcane plant crop for the experiments at the São Luiz and Santa Adélia Sugar Mills for the treatments 40, 80 and 120 kg/ha of N.

Analysing the participation of N fertiliser throughout the growth cycle of the plant cane (Figure 1), this participation proved to be low at harvest of the crop (around 10% of the total N accumulated by plant cane). This information, when analysed in an isolated way, may lead to over-hasty conclusions regarding the importance of nitrogen fertilisation in the nutrition of the plant cane.
and, to a lesser degree in ratoon cane. Since, in most studies with application of fertilisers labelled with $^{15}$N in sugarcane, evaluation is undertaken at harvest of the crop, a great deal of information and explanations regarding the effects of N fertiliser in plant nutrition are not addressed.

However, when the contribution of N fertiliser is evaluated throughout the plant cane cycle, there proves to be a contribution of approximately 40% of total N of the crop in the first stages of evaluation (Figure 1). What is the importance of this information regarding nutrition of the plant cane? The answer is in the accumulation of N fertiliser in the cell vacuoles in the form of $\text{NO}_3^-$ or assimilated as glutamate (Taiz and Zeiger, 2009), for later use.

In this sense, the plants, after absorbing the N fertiliser in the initial stages of growth, would enter in dormancy due to the beginning of the fall-winter seasons, characterised by climatic conditions adverse to plant development (low temperatures, lack of rain, water deficit and short days); with the spring, when the climatic conditions come to be favourable for the growth of sugarcane (beginning of rains and increase in temperature), the plants use this N reserve to help in their metabolism. Therefore, plants that received N fertiliser at the beginning of the crop cycle would have greater growth and development potential due to their greater reserve of N accumulated in the initial stages of growth. That way, in environmental conditions favourable to the development of the plant, the crop would respond in terms of productivity to the nitrogen fertilisation in comparison to the non-fertilised plants, even with the N fertiliser representing a small fraction of the total N (10 to 20%) of the plant when evaluated at harvest of the plant cane.

**Ratoon crop cycle**

After the harvest of the plant cane, the rates of N fertiliser were applied over the straw residue when the plants of the first regrowth were around 90 days of growth (October 8 and November 1, 2006 in the experiments at USL and USA, respectively). Later, in December 2006, the first estimate of the contribution (accumulation) of N fertiliser in the above ground part of the ratoon cane was undertaken. The results showed that, in this first evaluation time, the plants had absorbed practically all the fertiliser-N accumulated throughout the growth cycle of the crop; there was no statistical difference between the accumulated fertiliser-N in the plants (kg/ha) between the periods of evaluation within each treatment (Table 3).

**Table 3**—Estimate of the nitrogen in the plant derived from fertiliser (NDFF) during the cycle of the first regrowth in the São Luiz and Santa Adélia Sugar Mills experiments (2006/2007 harvest).

<table>
<thead>
<tr>
<th>Treatments (kg/ha)</th>
<th>São Luiz Sugar Mill</th>
<th>Santa Adélia Sugar Mill</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>December</td>
<td>March</td>
</tr>
<tr>
<td>120–0</td>
<td>1.2 A</td>
<td>3.0 A</td>
</tr>
<tr>
<td>0–50</td>
<td>11.5 A</td>
<td>16.9 A</td>
</tr>
<tr>
<td>120–50</td>
<td>13.9 A</td>
<td>13.7 A</td>
</tr>
<tr>
<td>0–100</td>
<td>18.0 A</td>
<td>18.0 A</td>
</tr>
<tr>
<td>120–100</td>
<td>26.9 A</td>
<td>33.2 A</td>
</tr>
</tbody>
</table>

L.S.D. = 12.1 CV = 39%

L.S.D.: least significant difference; CV: coefficient of variation; *June/July: June at the São Luiz Sugar Mill and July at the Santa Adélia Sugar Mill.

Equal capital letters in the line do not differ among themselves by the Tukey test at 5 % probability.
The accumulation of total N in the above ground part of ratoon cane (Table 4) in this work presented the same tendency of accumulation as in the plant cane; in other words, at the end of the maximum growth phase of the crop (May 2007) the plants had already accumulated a large part of the total N obtained at harvest.

### Table 4—Accumulation of nitrogen in the above ground part of the sugarcane in the cycle of the first regrowth in the experiments at the São Luiz and Santa Adélia Sugar Mills (2006/2007 harvest).

<table>
<thead>
<tr>
<th>Treatments (kg/ha)</th>
<th>São Luiz Sugar Mill</th>
<th>Santa Adélia Sugar Mill</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>December</td>
<td>March</td>
</tr>
<tr>
<td>0–0</td>
<td>33 B</td>
<td>62 AB</td>
</tr>
<tr>
<td>120–0</td>
<td>17 C</td>
<td>52 BC</td>
</tr>
<tr>
<td>0–50</td>
<td>25 C</td>
<td>72 AB</td>
</tr>
<tr>
<td>120–50</td>
<td>28 B</td>
<td>73 A</td>
</tr>
<tr>
<td>0–100</td>
<td>33 B</td>
<td>70 B</td>
</tr>
<tr>
<td>120–100</td>
<td>37 B</td>
<td>66 AB</td>
</tr>
</tbody>
</table>

L.S.D. = 38 CV = 30%

Equal capital letters in the line do not differ among themselves by the Tukey test at 5% probability. L.S.D.: least significant difference; CV: coefficient of variation; *June/July: June at the São Luiz Sugar Mill and July at the Santa Adélia Sugar Mill.

As indicated and discussed in the plant cane, in the initial growth stages of first regrowth cycle, the N coming from the nitrogen fertilisation (NDFF) was one of the main sources of N for the crop, emphasising that, in some treatments, it represented around 70% of the total N of the above ground part (Figures 2 and 3).

With the development of the ratoon cane, the fertiliser-N diminished its participation in the total N in the above ground part of the sugarcane, representing, on average, 30% of the total N at harvest.

It is to be emphasised that this contribution is significantly greater than that observed for fertilisation of the plant cane, which was in the order of 5 to 10% of the total N of the above ground part.

This probably relates to the higher mineralisation rates of soil organic carbon expected from tillage in the plant crop. Sampaio et al. (1984) found that the contribution of N from urea for the rates of 20 and 60 kg/ha of N was less than 10% of the total accumulated in the entire sugarcane plant.

Trivelin et al. (2002) obtained values of 11.5% for plant cane for the rates of N of 30, 60 and 90 kg/ha applied as urea. Gava et al. (2001) verified that the N in the plant coming from fertiliser...
represented 10 to 16% of the total accumulated N in the above ground part of the ratoon crop, while Trivelin et al. (1995) obtained a value less than 15% in ratoon cane at harvest.

Fig. 2—Nitrogen derived from the fertiliser (NDFF) in the total N of the above ground part of first ratoon crop in the experiment at the São Luiz Sugar Mill for the treatments 120-0 (the residual effect was evaluated from the dose of 120 kg/ha of 15N-urea on the plant cane and without fertilisation with N on the first ratoon); 0–50 (without fertiliser-N on the plant cane and 50 kg/ha of N with 15N-ammonium sulfate on the first ratoon); 120–50 (120 kg/ha of urea-N on the plant cane and 50 kg/ha of N with 15N-ammonium sulfate on the first ratoon); 0–100 (without N on the plant cane and 100 kg/ha of N as 15N-ammonium sulfate on the first ratoon); 120–100 (120 kg/ha of urea-N on the plant cane and 100 kg/ha N of 15N-ammonium sulfate on the first ratoon).
Fig. 3—Nitrogen derived from the fertiliser (NDFF) in the total N of the above ground part of first ratoon season in the experiment at the Santa Adélia Sugar Mill for the treatments 120–0 (the residual effect was evaluated from the dose of 120 kg/ha of $^{15}$N-urea on the plant cane and without fertilisation with N on the first ratoon); 0–50 (without fertiliser-N on the plant cane and 50 kg/ha of N with $^{15}$N-ammonium sulfate on the first ratoon); 120–50 (120 kg/ha of urea-N on the plant cane and 50 kg/ha of N with $^{15}$N-ammonium sulfate on the first ratoon); 0–100 (without N on the plant cane and 100 kg/ha of N as $^{15}$N-ammonium sulfate on the first ratoon); 80–100 (80 kg/ha of urea-N on the plant cane and 100 kg/ha of N with $^{15}$N-ammonium sulfate on the first ratoon) 120–100 (120 kg/ha of urea-N on the plant cane and 100 kg/ha N of $^{15}$N-ammonium sulfate on the first ratoon).

Conclusion

During the entire stage of growth of the ratoon cane, the contribution of fertiliser-N was greater than that of the plant cane, providing evidence that, in regrowth of sugarcane, in which there is little soil tillage, together with the maintenance of crop residues on the soil surface, the N fertiliser is one of the most important sources of the nutrient for the crop.
REFERENCES


L’AZOTE DE LA CANNE A SUCRE PROVENANT DES ENGRAIS

Par
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C.E. FARONI, A.C. VITTI et E.C.A. OLIVEIRA

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MOTS-CLES: Canne Récoltée en Vert, Urée Marquée avec $^{15}$N,
Paillis de Canne, Saccharum Spp.

Résumé

La fertilisation azotée en culture de canne à sucre est une pratique universellement utilisée pour atteindre des niveaux durables de productivité, à la fois en canne plantée et spécialement en repousse. Cependant, lors de l’évaluation à la récolte de l’azote de la plante provenant des engrais ($^{15}$N), on observe que cette contribution est de l’ordre de 20% de l’azote total mobilisé; ce qui pose des questions concernant l’efficacité de cette fertilisation. Aussi, des essais furent réalisés sur deux sites, avec de la canne à sucre mécaniquement récoltée en vert; localisés dans l’état de Sao Paulo, Brésil. La fertilisation azotée de la canne plantée (doses de 40; 80 et 120 kg/ha de N sous forme d’urée) et de la repousse (doses de 50 et 100 kg/ha sous forme de sulfate d’ammonium) fut marquée à l’aide de l’isotope stable $^{15}$N. En canne plantée, la contribution des engrais représentait 40% de l’azote total de la plante lors des étapes initiales de croissance, puis décroissait durant les stades de pré-maturité et maturité pour atteindre 10% à la récolte. En repousse, la contribution des engrais à la nutrition minérale fut plus efficace, avec 70% de l’azote total de la plante provenant des engrais dans les étapes initiales de croissance, spécialement pour les doses élevées en azote, puis diminua jusqu’à la récolte de la première repousse. Néanmoins, on remarqua que, pendant toute la croissance de la repousse, la contribution de l’azote de l’engrais fut plus élevée que celle de la canne plantée, de l’ordre de 30% de l’azote total de la plante. Ceci confirme que la fertilisation azotée de la repousse, avec peu ou pas de travail du sol, associé avec le maintien des résidus en surface, est une des sources d’azote les plus importantes pour la culture.
NITROGENO DERIVADO DEL FERTILIZANTE EN CAÑA DE AZUCAR

Por


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PALABRAS CLAVE: Caña Verde, $^{15}$N Urea Marcada, Residuos de Caña, Saccharum spp.

Resumen

La fertilización nitrogenada en el cultivo de caña de azúcar es una práctica universal utilizada para alcanzar niveles sostenibles de la productividad, tanto en la plantilla y sobre todo del segundo ciclo en adelante. Sin embargo, cuando se evalúa en la plantilla el N derivado del fertilizante ($^{15}$N) al momento de cosecha, se observa que esta contribución es del orden del 20% del N total, lo que da lugar a preguntas acerca de la eficiencia de la fertilización. Por lo tanto, se llevaron a cabo dos experimentos de campo en dos lugares cosechados mecánicamente y sin quema de la caña de azúcar en el Estado de São Paulo, Brasil. La fertilización con nitrógeno, tanto en la plantilla (40, 80 y 120 kg/ha de N como urea) y primera soca (50 y 100 kg/ha de N como sulfato de amonio), fueron marcados con el isótopo estable $^{15}$N. Se observó que el N de la fertilización nitrogenada representa hasta el 40% del N total de la caña en la plantilla en las etapas iniciales de su crecimiento, disminuyendo en las etapas de pre-madurez y madurez a niveles del orden del 10% en la cosecha. En las socas, la participación del fertilizante nitrogenado en la nutrición del cultivo fue más efectiva, constituyendo hasta el 70% del N total durante las etapas iniciales de desarrollo, especialmente cuando se aplicaron altas tasas de N, disminuyendo a través del ciclo de la primera soca. Sin embargo, se destaca que, durante todo el crecimiento de la soca, la contribución de los fertilizantes nitrogenados fue mayor que durante la plantilla, alcanzando el 30% del N total de la planta. Esto confirma que la fertilización con N en las socas, con poca o ninguna labranza del suelo, junto con el mantenimiento de residuos en la superficie del suelo, es una de las fuentes más importantes de N para el cultivo.
UTILISATION OF NITROGEN FROM TRASH BY SUGARCANE RATOONS

By

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KEYWORDS: Sugarcane, Nitrogen, Residue, Trash, Organic Matter, Fertility of Soil, Nutrition, ^15^N.

Abstract

A LARGE AMOUNT of crop residue (dry leaves, stem pieces and tips) remains on the soil surface after mechanical harvesting of unburnt sugarcane. These residues are often referred to as straw or trash and are a source of nutrients for following crops. In order to evaluate the ability of sugarcane to recover the nitrogen (N) from this trash, three experiments were carried out in Santa Adélia (SA), São Martinho (SM) and São Luiz (SL) Sugarcane Mills located in São Paulo State, Brazil, in two consecutive crop seasons (2006 and 2007). Microplots (1.5 x 2.0 m), replicated four times in a randomised block design, were installed at the start of a 1st ratoon crop of the variety SP 81-3250. No fertiliser N was applied to the microplots. The field crop residues in the microplots were replaced with 10 t/ha DM of ^15^N labelled trash. The rate of trash-N and ^15^N abundances were 41, 41 and 51 kg/ha and 1.01, 0.83, and 1.00 atom % for SA, SM and SL experiments, respectively. The highest ^15^trash-N uptake was observed in the 1st ratoon crop in the SL experiment (4.3 kg/ha Trash-N), followed by SM and SA experiments (3.8 and 3.1 kg/ha of Trash-N). For the 2nd ratoon crop (2008), Trash-N recoveries could only be determined for the SA and SM experiments due to an accidental firing in the SL experiment. The SA experiment had the highest Trash-N uptake in the 2nd ratoon crop and was more than double the Trash-N recovery measured in the 1st ratoon crop. Nitrogen recovery from the trash on SM was 0.8 kg/ha of N, substantially lower than that observed in the 1st ratoon crop. After two crops (1st and 2nd ratoon crops), the total Trash-N recovered was 3.9 kg/ha (9.8%) and 9.6 kg/ha (23%), for SM and SA experiments, respectively.

Introduction

When sugarcane is mechanically harvested without previous burning, a considerable amount of dry leaves, pieces of stem and tip remains on the surface, forming a vegetable residue covering called trash or straw. This trash promotes changes in the nitrogen (N) cycle, mainly due to the immobilisation and mineralisation reactions mediated by microorganisms. In addition, these residues will serve as a source of nutrients for the soil macro and microflora as well as for the sugarcane crop (Wood, 1991).

The amount of sugarcane trash after an un-burnt harvest, can vary from 10 to 30 t/ha of dry matter and containing about 40 to 80 kg/ha of N (Oliveira et al., 2002; Vitti et al., 2007) which can
lead to an increase in the amount of organic matter and nutrients in the soil (Wood, 1991; Vallis et al., 1996).

The mineralisation of crop residues (trash) added to soil is mainly dependent on the quality (chemical composition) of crop residues as well as environmental factors such as temperature, humidity, and soil aeration. The quality of the trash is typically defined by the C:N ratio, contents of lignin, cellulose, hemicellulose, and polyphenols (Ng Kee Kwong et al., 1987, Oliveira et al., 2002). The organic complexes from the trash mineralisation, such as humic acid, accumulate in the soil because of their high degree of recalcitrance and resistance to microbial attack. Therefore, the components that control the kinetics of the transformation of the organic N to inorganic N in the organic matter are various and complex (Janssen, 1996).

The sugarcane trash, on average, contains 390 to 450 g/kg of carbon and 4.6 to 6.5 g/kg of N (Ng Kee Kwong et al., 1987; Oliveira et al., 2002), which indicates an average C:N ratio of 100. Under these conditions, a strong immobilisation of N from soil and a small net mineralisation in just one agricultural year is expected (Gava et al., 2005). Residues that present nitrogen content lower than 18 g/kg and C:N ratio above 20 usually enable immobilisation (Janssen, 1996; Jingguo and Bakken, 1997). Thus, the contribution of N from the trash to the crop mineral nutrition may be small, since the decomposition of these residues with high C: N ratio promotes a competition between roots and soil microorganisms for the N available in the system (Jingguo and Bakken, 1997).

In a study performed by Vitti et al. (2005) to assess the trash-\(^{15}\)N recovery in sugarcane second ratoon (3rd harvest), it was observed, after one year, that 73% of the total N present in the trash, remained in the trash, 22% in soil and only 4% was recovered by the plant. Despite the small contribution of N from trash to the crop nutrition in the first year of residence in the field, most of the N accumulated by sugarcane occurred in the last months before the harvest. Therefore, the largest contribution of N from trash may occur in the following crop seasons, since more than 20% of the nutrient remained in the soil, besides decreasing the C: N residue ratio over time.

In this way, the work presented here aimed to assess the utilisation of mineralised N from residual trash (trash-N) by the sugarcane crop, during the period after the harvest of the plant crop till the harvest of the 2nd ratoon (2007, 2008) using the \(^{15}\)N isotope tracer technique.

**Material and methods**

The experiment was conducted in three areas cultivated with sugarcane which were mechanically harvested without burning, located in São Paulo State, Brazil. The areas belonged to, respectively, the Santa Adélia (SA) (Latitude 21°15’S, Longitude 48°18’W), the São Martinho (SM) (Latitude 21°15’S, Longitude 48°18’W) and São Luiz Sugarcane Mills (SL) (Latitude 21°59’S, Longitude 48°02’W). The soil is an Arenic Kandiustults (Latosolso Vermelho distrófico) in SA, a Rhodic Eutrustox (Latosolso Vermelho eutrófico) in SM and a Typic Eutrustox (Latosolso Vermelho amarelo eutrófico) in SL, according to Soil Survey Staff (2003) and Embrapa (2006), respectively. The soil analysis was conducted in the three locations at 0-25 and 25–50 cm depth, after harvesting the plant-cane (Table 1).

The planting was performed in February for SL, March for SM and in April 2005 for SA, in which 17 to 20 buds/m of SP81-3250 sugarcane cultivar were distributed. In the bottom of the furrows we applied 120 kg/ha of K\(_2\)O as potassium chloride, 120 kg/ha P\(_2\)O\(_5\) as simple superphosphate and 80 kg/ha as urea.

After harvesting the plant-cane, the experiment was installed in randomised blocks with 4 replicates. Each experimental plot consisted of 12 rows, 15 metres long and 1.5 m row spacing. In October 2006, microplots (2 m length and 1.5 m width) were installed. Within the microplots, residual trash from the mechanical harvesting was replaced by trash labelled with the \(^{15}\)N isotope equivalent to 10 t/ha DM. The trash was coming from an experiment with nitrogen fertilisation employing \(^{15}\)N-fertiliser (urea enriched with 5.04% in \(^{15}\)N atoms) and presented \(^{15}\)N enrichment of
1.01% (SA), 0.83% (SM) and 1.00% (SL) in $^{15}$N atoms. The total amount of N present in the residues was equivalent to 41, 41 and 51 kg/ha for the 1st ratoon for SA, SM and SL respectively. Results from the 2nd ratoon (2008) for SL were not collected due to an accidental fire in the experimental area.

Table 1—Soil analysis at 0–25 and 25–50 cm depth, of the three experimental areas of São Luiz (SL), Santa Adélia (SA) and São Martinho (SM) Sugarcane Mills, performed after the first sugarcane harvest.

<table>
<thead>
<tr>
<th>Sugarcane mill</th>
<th>Depth</th>
<th>S.O.M.</th>
<th>pH</th>
<th>P</th>
<th>S</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>H+Al</th>
<th>BS</th>
<th>CEC</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cm</td>
<td>g/dm³</td>
<td>CaCl₂</td>
<td>mg/dm³</td>
<td>mmol/dm³</td>
<td>%</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
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<td>2</td>
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<td>35</td>
<td>9</td>
<td>15</td>
<td>45.4</td>
<td>60.4</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>25–50</td>
<td>16</td>
<td>5.2</td>
<td>2</td>
<td>12</td>
<td>1.4</td>
<td>14</td>
<td>4</td>
<td>19</td>
<td>19.1</td>
<td>38.6</td>
<td>49</td>
</tr>
<tr>
<td>SA</td>
<td>0–25</td>
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<td>5.4</td>
<td>15</td>
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<td>35</td>
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<td>4.3</td>
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<td>10</td>
<td>32</td>
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</tbody>
</table>

The 1st ratoon harvest was performed in July 2007 (SA and SL) and in August 2007 (SM). The above-ground parts of the plants located in 1 m of furrow in the centre of each microplot and beside each one of the microplots were harvested manually. The samples were separated into dry leaves, tips and stems. The mass of trash was determined directly in the field. All the material from the microplots was ground in a mechanical forage chopper.

After grinding and homogenising each wet sample, a subsample was taken, which was weighed and dried in an oven (72 hours at 65°C), and the dry mass and the moisture content of the material were determined. The dry material was ground in a Wiley mill and analysed by mass spectrometry for total N (%) and $^{15}$N abundance (% in $^{15}$N atoms).

The remaining rows of the plots were harvested by mechanical harvester. After the harvest of the 1st ratoon, the experimental plots and microplots were maintained. In the microplots, the unlabelled trash of the 1st ratoon overlapped the labelled trash-$^{15}$N of the plant-cane.

Nitrogen fertiliser was not used in the ratoon, so that the effect of the trash-$^{15}$N recovery could be isolated. The second ratoon crop was harvested in July 2008, and the procedure adopted was the same as the previous season. The nitrogen in the plant derived from trash (NPDS) and the N utilisation (NR) from the aerial part were calculated using the equations:

\[
NPDS = \frac{[(A - C) / (B - C)].NT}{100}
\]

\[
NR (%) = \frac{(NPDS / NAF)}{100}
\]

where: NPDS = N in the plant from the trash-$^{15}$N (kg/ha); NR = utilisation of trash-$^{15}$N by the aerial part of the plant (%); A = $^{15}$N abundance (atoms %) of the plant; B = $^{15}$N abundance (1.01%-SA, 0.83%-SM and 1.00%-SL atoms %) of the labelled trash; C = $^{15}$N natural abundance (0.366% of atoms); NT = N content of the plant (kg/ha); NAF = amount of N in the trash (kg/ha).

The results were submitted to analysis of variance and, when F was significant, the means were compared by Tukey test at 1% probability.

During the experimental period, the amount of rainfall and the average maximum and minimum temperature were measured in automatic stations installed near to the experimental areas (Figure 1).
Results and discussion

At the end of the 1st ratoon cycle, the above-ground plant components accumulated approximately 3.8, 3.0 and 4.3 kg/ha of N, which corresponds to a recovery of 9.5, 7.3 and 8.4% of nitrogen (^{15}N) in the initial crop residues for SA, SM and SL, respectively (Table 2). For the three areas, the results are similar to those presented by Ng Kee Kwong et al. (1987) and Gava et al. (2005), who observed from 5 to 14% of the N-total presented in the trash was recovered by above-ground parts of sugarcane. For the 2nd ratoon, the recovery of trash^{15}N in the field was 6.6 kg/ha (17.7%) for SA and 0.8 kg/ha (2.1%) for SM (Table 2).

The total recovery of trash-N by the sugarcane after two years was 3.9 kg/ha (9.6%) for SM and 9.6 kg/ha (23%) for SA, showing a small contribution to the nitrogen nutrition of sugarcane. Meier et al. (2006) showed that trash supplies N slowly and in small amounts to the succeeding crop, and N mineralisation from a single trash blanket is not important for sugarcane production in the wet tropics. Among the plant components, the largest recoveries of trash-N were observed in the
stems, regardless of nitrogen fertilisation, followed by the tip and dry leaf components. The greater allocation of N in the stem is due to the greater mass of this compartment in relation to the dry leaf and tip (Table 3).

Although the recovery for the 1st ratoon at SL site was not the largest one (8.4%), it presented the best results (4.3 kg/ha), probably due to the greater accumulation of total N present in the trash (51 kg/ha) in relation to the SA and SM areas (41 kg/ha).

For SA site, the trash-N recovery for the 2nd ratoon was double that observed in the 1st ratoon. This result was higher than those found by Ng Kee Kwong et al. (1987) and Gava et al. (2005). The greater utilisation by sugarcane of trash-N in the 2nd ratoon is mainly due to the decrease in the C: N ratio with the trash decomposition, favouring mineralisation instead of immobilisation. The mineralisation of residues depends, therefore, on the material C:N ratio, besides the quality of the residue (Oliveira et al., 2002) and the degree of partition and transfer (‘turnover’) in the soil of the mineralised nitrogen of vegetal residue (Myers et al., 1994). Those authors reported that during the decomposition of crop residues, there is a partitioning of N into the mineral N (soil and fertiliser) pool, N-humic pool and N-immobilised by the microbial biomass of the soil, as well as a continuous transfer (‘turnover’) of this N between the compartments. Jadhav (1996) observed, over time, that through the trash decarboxylation, CO₂ was released, keeping the N in the system, resulting in a decrease in C:N ratio from 120:1 to 20:1. This close relationship to the microorganisms C:N ratio (about 12:1) intensifies the mineralisation, increasing the N pool in soil from the trash decomposition, resulting in a greater N availability for the plants.

Table 2—Recovery from trash-N by the above-ground plant components (stem, tip and dry leaf), respectively, of the 1st and 2nd ratoon crops (2006/07 and 2007/08 seasons) for the Santa Adélia (SA), São Martinho (SM) and São Luiz (SL) sugarcane mill areas.

<table>
<thead>
<tr>
<th>Sugarcane mill</th>
<th>Parts of plant</th>
<th>Trash-N recovery</th>
<th>NPDS&lt;sub&gt;total&lt;/sub&gt; (kg/ha)</th>
<th>R(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>First ratoon (2006/07)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SA</td>
<td>Stem</td>
<td>2.6 ± 0.2</td>
<td>5.7 ± 0.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dry leaf</td>
<td>0.6 ± 0.0</td>
<td>1.4 ± 0.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tip</td>
<td>0.9 ± 0.1</td>
<td>2.4 ± 0.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aerial part</td>
<td>3.8 ± 0.2</td>
<td>9.5 ± 0.6</td>
<td></td>
</tr>
<tr>
<td>SM</td>
<td>Stem</td>
<td>1.7 ± 0.3</td>
<td>4.2 ± 0.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dry leaf</td>
<td>0.5 ± 0.1</td>
<td>1.2 ± 0.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tip</td>
<td>0.9 ± 0.1</td>
<td>2.1 ± 0.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aerial part</td>
<td>3.1 ± 0.6</td>
<td>7.5 ± 0.3</td>
<td></td>
</tr>
<tr>
<td>SL</td>
<td>Stem</td>
<td>2.0 ± 0.6</td>
<td>3.9 ± 1.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dry leaf</td>
<td>1.2 ± 0.2</td>
<td>2.3 ± 0.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tip</td>
<td>1.1 ± 0.4</td>
<td>2.2 ± 0.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aerial part</td>
<td>4.3 ± 0.7</td>
<td>8.4 ± 1.4</td>
<td></td>
</tr>
<tr>
<td>Second ratoon (2007/08)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SA</td>
<td>Stem</td>
<td>2.6 ± 1.5</td>
<td>6.9 ± 4.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dry leaf</td>
<td>0.4 ± 0.2</td>
<td>1.0 ± 0.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tip</td>
<td>3.5 ± 2.5</td>
<td>9.4 ± 6.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aerial part</td>
<td>6.5 ± 4.2</td>
<td>17.3 ± 11.5</td>
<td></td>
</tr>
<tr>
<td>SM</td>
<td>Stem</td>
<td>0.4 ± 0.1</td>
<td>1.1 ± 0.4</td>
<td></td>
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<tr>
<td></td>
<td>Dry leaf</td>
<td>0.1 ± 0.0</td>
<td>0.3 ± 0.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tip</td>
<td>0.3 ± 0.0</td>
<td>0.7 ± 0.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aerial part</td>
<td>0.8 ± 0.1</td>
<td>2.1 ± 0.4</td>
<td></td>
</tr>
</tbody>
</table>

1 NPDS<sub>total</sub> = NP<sub>1</sub>*DS<sub>1</sub> + 2 NP<sub>1</sub>*±1DS<sub>1</sub> (Trivelin et al., 1994). Mean and standard deviation (m ± sm) of 4 replicates.
At the SM experiment site, there was a decrease in the utilisation of N in the 2\textsuperscript{nd} ratoon in relation to the 1\textsuperscript{st} ratoon. This is probably due to the reduced productivity of 2\textsuperscript{nd} ratoon in relation to the 1\textsuperscript{st} ratoon, resulting in a lower accumulation of total N in the above-ground plant material. On the other hand, most of the nitrogen mineralised in the 1\textsuperscript{st} ratoon cycle is located in the part of the trash which easily decomposes, linked to compounds such as sugars, cellulose, free amino acids, proteins, nucleic acids and nucleotides (Killham, 1994). Therefore, the N remaining in the trash for utilisation by the 2\textsuperscript{nd} ratoon crop is found in compounds more recalcitrant to microbial attack, such as lignin and polyphenols (Paul and Clark, 1996), impeding the mineralisation process. The trash-\textsuperscript{15}N recovery by the 2\textsuperscript{nd} ratoon may also be affected by the root system ageing since, during the course of the crop, the sugarcane roots consist of less fibrous roots and a lower proportion of the root hairs, which results in lower efficiency of nutrients and water absorption (Vasconcelos and Casagrande, 2008).

| Table 3—Production of dry matter and nitrogen accumulated in the above-ground plant components (stem, tip and dry leaf) for the 1\textsuperscript{st} and 2\textsuperscript{nd} ratoon crops for Santa Adélia (SA), São Martinho (SM) and São Luiz (SL) Sugar Mill. |
| Sugarcane mill | Parts of plant | Dry matter (t/ha) | Nitrogen accumulation (kg/ha) |
| SA | Stem | 26 ± 1.3 | 50 ± 5 |
| | Dry leaf | 10 ± 0.3 | 33 ± 2 |
| | Tip | 4 ± 0.2 | 43 ± 5 |
| SM | Stem | 24 ± 0.3 | 56 ± 11 |
| | Dry leaf | 8 ± 0.1 | 23 ± 7 |
| | Tip | 7 ± 0.1 | 53 ± 14 |
| SL | Stem | 17 ± 0.9 | 31 ± 4 |
| | Dry leaf | 8 ± 0.3 | 31 ± 2 |
| | Tip | 4 ± 0.2 | 40 ± 5 |
| SA | Second ratoon (2007/08) | Stem | 22 ± 1.7 | 43 ± 4 |
| | Dry leaf | 3 ± 0.4 | 9 ± 3 |
| | Tip | 6 ± 0.2 | 50 ± 10 |
| SM | Stem | 12 ± 0.7 | 33 ± 4 |
| | Dry leaf | 4 ± 0.3 | 13 ± 2 |
| | Tip | 2 ± 0.2 | 16 ± 4 |

\(^{1}\) Mean and standard deviation (m ± sm) of 4 replicates.

The precipitation rates and the mean temperatures were also lower in the 2007/2008 period compared to 2006/2007 period, which may have affected the trash decomposition, since it is favoured by high temperatures and high humidity. It was noted by Stanford \textit{et al.} (1973) and Katterer \textit{et al.} (1998) that, in the range 5 to 35°C, the mineralisation rate doubles every 10°C of temperature increase.

In work done by Quemada and Cabrera (1997), in which the organic matter of \textit{Trifolium incarnatum} L. was placed on the soil surface, a decrease in mineralisation of about 20% was found, when the soil incubation temperature decreased from 28 to 20°C. In line with this reasoning, the higher recovery of the 2\textsuperscript{nd} ratoon in the SA can be explained, considering that it presented the most favourable conditions of temperature and humidity in relation to the 1\textsuperscript{st} ratoon (Figure 1).

When quantifying the trash-N recovery, it may be necessary to also take into account the translocation of N from the above-ground plant components to the root system mainly during the sugarcane maturation, as suggested by Vitti \textit{et al.} (2007). Therefore, the recovery may be greater than that presented here if the N in roots and rhizomes was accounted for. Vitti \textit{et al.} (2007) observed that the root system of sugarcane can be on average 1/3 of total N accumulated by shoots.
Although the sugarcane crop residues have presented low amounts of N available for uptake by the crop, the trash deposited in the soil in successive harvests can contribute to a greater accumulation of organic N in the soil, up to 79% of N can be retained in the soil, as observed by Robertson and Thorburn (2007). Studies conducted in Australia by Vallis et al. (1996) indicate that the sugarcane trash left on the soil surface for a period of 20 years may result in the reduction of up to 40 kg/ha in N fertilisation. Thus, the crop residues generated by mechanical harvesting without the use of fire to burn trash represent an important stock of nitrogen in the soil-plant system, and certainly they will contribute to a reduction in N rates used in ratoons cultivated in Brazil.

Conclusion

The trash-N recovery was significant in the two year period of this experiment, ranging from 7.5% to 9.5% and 2.2% to 17.7% in 1st and 2nd ratoons, respectively.

The lower utilisation of trash-N in the experimental site located in the São Martinho Sugarcane Mill area could be attributed to the less favourable weather conditions in relation to other areas, resulting in a lower mineralisation rate of the residues. The participation of trash-N in the sugarcane ratoons nutrition represented a small part of the total N. However, over many years, this N source may help in reducing N rates employed in the agricultural system as suggested in similar studies in other regions.

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REFERENCES


UTILISATION DE L’AZOTE DES PAILLES PAR LES REPOUSSES DE CANNE A SUCRE

Par

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MOTS-CLES: Canne à Sucre, Azote, Résidus, Paille,
Matière Organique, Fertilité Des Sols, Nutrition, 15N.

Résumé
UNE GRANDE quantité des résidus de récolte (feuilles sèches, morceaux de tiges, et bouts blancs) restent à la surface du sol après la récolte mécanique de canne sans brûlage. Ces résidus, souvent appelés paille sont une source d’éléments nutritifs pour les récoltes suivantes. Afin d’évaluer la capacité de la canne à récupérer l’azote de ces pailles, trois expérimentations ont été conduites à Santa Adélia (SA), São Martinho (SM) et São Luiz (SL), sucreries situées dans l’état de São Paulo, Brésil, pendant deux campagnes consécutives (2006 et 2007). Des micro-parcelles (1.5 × 2.0 m) répétées 4 fois selon un dispositif en bloc randomisé, ont été installées en début de 1ère repousse de la variété SP 81-3250. Aucune fertilisation azotée n’a été appliquée dans les micro-parcelles et les résidus de récolte dans les micro-parcelles ont été remplacés par 10 t/ha de matière sèche de paille marquée avec de l’azote 15N. Les doses de N du paillis et d’abondance en 15N furent respectivement de 41, 41 et 51 kg/ha et fr 1.01, 0.83 et 1.00 de % d’atome pour les essays SA, SM et SL. La plus forte assimilation de 15N provenant des pailles a été observée dans la première repousse de l’expérimentation de SL (4.3 kg/ha de N-paille), suivie par les expérimentations de SM et SA (3.8 et 3.1 kg/ha de N-paille). En 2ème repousse, la récupération de l’azote provenant des pailles n’a pu être déterminée que pour les expérimentations de SA et SM, suite au feu accidentel survenu dans celle de SL. L’expérimentation de SA a eu le plus fort taux de prélèvement d’azote en provenance de la paille en 2ème repousse, soit plus du double de ce qui avait été mesuré en 1ère repousse. L’azote en provenance de la paille à SM a été de 0.8 kg/ha, soit bien plus bas que ce qui avait été observé en 1ère repousse. Après deux années de culture (1ère et 2ème repousse), la quantité totale de N en provenance des pailles a été respectivement de 3.9 kg/ha (9.8%) et 9.6 kg/ha (23%) pour SM et SA.
UTILIZACIÓN DEL NITRÓGENO A PARTIR DEL TRASH POR LAS CAÑAS SOCAS

Por

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PALABRAS CLAVES: Caña de Azúcar, Nitrógeno, Residuo, Trash, Materia Orgánica, Fertilidad del Suelo, Nutrición, 15N.

Resumen

Después de la cosecha mecánica de la caña en verde (sin quema), queda sobre la superficie del suelo una gran cantidad de residuos del cultivo (hojas secas, trozos de tallo y despunte). A estos residuos se los conoce frecuentemente como paja o trash y son una fuente de nutrientes para los cultivos subsiguientes. Con el objetivo de evaluar la capacidad de la caña de azúcar para recuperar nitrógeno (N) a partir de este residuo, se realizaron tres experiencias en los ingenios azucareros Santa Adélia (SA), São Martinho (SM) y São Luiz (SL), ubicados en el estado de San Pablo, Brasil, durante dos ciclos sucesivos de cultivo (2006 y 2007). Se trabajó con la variedad SP 81-3250, en la edad de primera soca, utilizando microparcels (1.5 × 2.0 m) en un diseño experimental de bloques al azar con cuatro repeticiones. En las microparcels no se realizó fertilización nitrogenada. El residuo de la cosecha en las microparcels fue remplazado por el equivalente a 10 t/ha (materia seca) de trash marcado con 15N. La tasa de trash-N y 15N fue 41, 41 y 51 kg/ha y 1.01, 0.83, y 1.00 átomo % para las experiencias en SA, SM y SL, respectivamente. La mayor absorción de 15N se observó en la soca 1 de la experiencia en SL (4.3 kg/ha de N del trash), seguida por las experiencias en SM y SA (3.8 y 3.1 kg/ha de N del trash). Para la edad de soca 2 (2008), la recuperación de N del trash solo pudo ser determinada para las experiencias en SA y SM, debido a un incendio accidental en la experiencia de SL. En la soca 2 la experiencia de SA presentó la más alta absorción de N del trash y fue más del doble de la recuperación de N del trash medida en la soca 1. La recuperación de N a partir del trash en SM fue de 0.8 kg de N/ha, sustancialmente menor que la observada en la primera soca. Después de dos ciclos de cultivo (1º y 2º soca) el total de N recuperado del trash fue 3.9 kg/ha (9.8%) y 9.6 kg/ha (23%), para las experiencias de SM y SA, respectivamente.
THE IMPACT OF REDUCED NITROGEN FERTILISER APPLICATION RATES ON NITROGEN LOADS TO SURFACE WATER

By

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KEYWORDS: Nitrogen Replacement, Runoff, Fertiliser, Urea.

Abstract

NITROGEN losses to water from farming systems have the potential to negatively impact human and ecosystem health. Environmental damage to the Great Barrier Reef as a result of extra nitrogen inputs since European settlement is becoming increasingly apparent. Sugarcane is the dominant intensive landuse in Great Barrier Reef catchments, and consequently this industry’s nitrogen management practices are coming under increasing scrutiny and pressure to implement nitrogen management practices that reduce losses of nitrogen to the environment. An experiment was conducted in sugarcane on the Wet Tropical coast of Australia to measure nitrogen losses from two different rates of nitrogen fertiliser to surface water. Results show that substantial decreases in nitrogen application rate reduced nitrogen lost to surface water by 34%. Between 10 and 15 kg N/ha/y was lost in runoff water as total nitrogen, which is agronomically insignificant, but aggregated over the whole sugarcane industry, may be detrimental to the health of the Great Barrier Reef. For the sugarcane industry to reduce losses of nitrogen for improved water quality, reducing fertiliser rates is an appropriate management option that can deliver lower nitrogen contributions to downstream ecosystems.

Introduction

Nitrogen is an essential element for plant growth, providing good returns on investment in agricultural cropping systems (FAO, 2006). However, nitrogen can be mobile in the crop-soil system, and has been detected in water downstream of agriculture (e.g. Mitchell et al., 2001).

In Australia, elevated levels of nitrogen, likely to be originating from agricultural fertiliser use, have been detected in the rivers draining to the World Heritage listed Great Barrier Reef (Mitchell et al., 2001; Bramley and Roth, 2002). This extra nitrogen is a cause for concern, possibly causing degradation of the Great Barrier Reef (Brodie et al., 2005); and potentially lowering the reefs resilience to climate change (Wooldridge, 2009).

Sugarcane (Saccharum spp.) is by far the dominant cropping landuse in catchments draining to the Great Barrier Reef, occupying c. 380 000 ha (Canegrowers, 2009). In Australia, sugarcane receives annual nitrogen fertiliser applications of 150+ kg nitrogen per hectare (Calcino et al., 2000); however, not all of the applied nitrogen is used by the crop (Thorburn et al., 2003). Australian sugarcane is also grown with high water input from either high rainfall in the wet tropics or in supplementary or full irrigation in drier catchments. The majority of sugarcane grown in Great Barrier Reef catchments is grown on the coastal lowlands, floodplains and deltas close to estuaries,
creeks and river mouths. This proximity to the end of catchments means there are very short residence times for water draining from sugarcane farms to the Great Barrier Reef lagoon, providing little opportunity for in-river processes to remove nitrogen from the flow (Furnas and Mitchell, 2001). This unique combination of high fertiliser nitrogen input, high water input, proximity to the end of catchments and, by virtue of being the dominant landuse, means it is important to manage sugarcane to minimise nitrogen losses from the paddock to protect the sensitive ecosystems of the Great Barrier Reef.

Nitrogen losses from sugarcane production systems to ground water have been extensively investigated (e.g. Ng Kee Kwong and Deville, 1984; Ghiberto et al., 2009; Stewart et al., 2006; Bohl et al., 2000). While nitrogen lost to leaching is an economic imposition on the farm manager, the environmental consequences of this nitrogen on surface water are uncertain (Rasiah et al., 2005). The few studies of nitrogen losses in surface water suggest losses may be small, in the range of a few up to approximately 20 kg N/ha (Ng Kee Kwong et al., 2002; Bengtson et al., 1998) but, given sugarcane’s proximity to the Great Barrier Reef, virtually all nitrogen lost in surface water flow from cane lands will enter the reef lagoon (Furnas and Mitchell, 2001). Additionally, when these agronomically small nitrogen losses are aggregated across the entire sugarcane industry, they could be contributing a substantial increase in nitrogen flow to the Great Barrier Reef.

Furthermore, there is little evidence as to what contribution changing management practice may have on reducing nitrogen losses to surface water. For this reason, we measured nitrogen losses to surface water from two application rates of nitrogen fertiliser over two years to determine if nitrogen fertiliser application rate management can be a useful tool for reducing surface water nitrogen losses and ultimately benefit the Great Barrier Reef.

**Materials and methods**

Data were obtained from an experimental site in the Saltwater Creek catchment, in the Mossman district of north Queensland (approximately 16°S, 145°E). This district is in the wet tropics bioregion and receives an average annual rainfall of 2018 mm/year (Bureau of Meteorology, 2009); however, the experimental site receives on average approximately 750 mm more per annum according to the farmer (S. McDonald, pers. comm.). The experimental site has a well drained soil formed on alluvium, described as dark greyish brown silty clay loam A horizon and yellowish brown silty clay loam to light clay B horizon with moderate fine blocky structure (Murtha 1994). Soil organic carbon is 1.2% in the top 20 cm.

The site has been growing sugarcane continuously since the mid 1970s, with the sugarcane stool being ploughed out, the block cultivated and replanted to sugarcane in the same year every four to six years. The site has been harvested green with the residue retained since the early 1980s. The site was last planted in August 2000 with the cultivar Q174® and has been harvested in September of each subsequent year (achieving 64 tonnes/ha in 2001, 103 tonnes/ha in 2002, and 89 tonnes/ha in 2003).

The experimental program was initiated after the 2003 harvest (4th September 2003) with the site divided into six plots, each 13 rows wide (at 1.57 metre row spacing), a row length of approximately 175 metres, and a single row between each plot. One of two nitrogen rates was randomly assigned to plots, being either a) the normal nitrogen rate the farmer applies (N_farm), equalling 186 kg N/ha and b) a nitrogen rate based on replacing the nitrogen exported in the previous crop (N_repl), using a multiplier of yield in tonnes/ha (based on Thorburn et al., 2004), equalling 102 kg N/ha (a multiplier of yield in tonnes multiplied by 1.15 to determine rate in kg N/ha was used). All fertiliser was applied as urea on the surface trash on 28th October 2003.

On 28th and 29th October 2003, two of the plots (one from each treatment) were instrumented to record water runoff volume and automatically sample runoff water during events. Each plot had a 9 inch Parshall flume (extended to capture runoff from 11 rows) equipped with a
monitoring station including an ISCO automatic water sampler which could collect up to 24 samples and store at 4°C prior to collection, a stage recorder located in a stilling well, and a pluviometer. The stage recorders, sample data and pluviometer were connected to a Campbell CR10X data logger, linked via telemetry to download hourly for remote monitoring. A ridge ran across the plots, with not all surface water running towards the sampling stations. Each plot was surveyed using total station surveying gear, with the Nfarm rate draining an area of 3300 m² with a slope of 0.65%, and the Nrepl rate draining an area of 2600 m² and a slope of 0.33%.

Over the 2003/04 wet season, water samples were collected after each triggered sampling event and retained frozen before being transported and analysed for total nitrogen.

During events, the Parshall flume stage height was recorded every minute, with stage height being converted to discharge for all of the stage data recorded over the six month wet season. Some corrections were necessary to the raw stage data when there was ponding of water in the base of flumes after small rainfall events. Flow weighted TN was calculated for each monitored event.

**Results**

The 2003/04 wet season’s first runoff event was in the beginning of December 2003, and there were 20 monitored events through to the end of May 2004 (Figure 1). A total of 2868 mm of rain was recorded during this period (Figure 1). There were two distinct periods of heavy rainfall during the 2003/04 season, with 492 mm falling between 29th February 2004 and 3rd March 2004 and 465 mm falling on the 18th and 19th of March 2004. Flood events occurred during these two events where runoff water below the flume backed up into the flume, meaning accurate measurement of runoff discharge was not possible. Estimates of runoff discharge during these periods were made.

Runoff coefficients varied between the events from 1 up to 76% of rainfall being monitored as runoff water. The total runoff coefficients for the two plots had a high level of agreement, with 23.9% for the Nfarm plot and 24.9% for the Nrepl plot.
The calculated event mean concentrations for the first events were the highest for the year (9.75 mg/L in the N_farm treatment and 3.87 mg/L in the N_repl treatment). Both treatments showed a steady decline in event mean concentration after the first event down to 0.93 mg/L in the N_farm treatment and 0.42 mg/L in the N_repl treatment. Calculated N loads (kg/ha) for total nitrogen delivery to surface water are presented in Table 1. TN loads are highest in the high runoff events, even though they have lower event mean concentrations.

**Table 1**—Loads of total nitrogen (TN) lost to surface water for all monitored events in the 2003/04 wet season from two rates of nitrogen fertiliser application.

<table>
<thead>
<tr>
<th>Event</th>
<th>N_repl (102 kg N/ha)</th>
<th>N_farm (186 kg N/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.05</td>
<td>0.13</td>
</tr>
<tr>
<td>2</td>
<td>0.40</td>
<td>1.00</td>
</tr>
<tr>
<td>3</td>
<td>0.22</td>
<td>0.77</td>
</tr>
<tr>
<td>4</td>
<td>1.88</td>
<td>1.95</td>
</tr>
<tr>
<td>5</td>
<td>0.33</td>
<td>0.47</td>
</tr>
<tr>
<td>6</td>
<td>0.11</td>
<td>0.18</td>
</tr>
<tr>
<td>7</td>
<td>2.30</td>
<td>3.24</td>
</tr>
<tr>
<td>8</td>
<td>0.07</td>
<td>0.13</td>
</tr>
<tr>
<td>9</td>
<td>0.78</td>
<td>1.03</td>
</tr>
<tr>
<td>10</td>
<td>0.06</td>
<td>0.07</td>
</tr>
<tr>
<td>11</td>
<td>2.14</td>
<td>2.51</td>
</tr>
<tr>
<td>12</td>
<td>0.28</td>
<td>0.33</td>
</tr>
<tr>
<td>13</td>
<td>1.25</td>
<td>2.86</td>
</tr>
<tr>
<td>14</td>
<td>0.01</td>
<td>0.03</td>
</tr>
<tr>
<td>15</td>
<td>0.05</td>
<td>0.11</td>
</tr>
<tr>
<td>16</td>
<td>0.05</td>
<td>0.10</td>
</tr>
<tr>
<td>17</td>
<td>0.03</td>
<td>0.06</td>
</tr>
<tr>
<td>18</td>
<td>0.04</td>
<td>0.09</td>
</tr>
<tr>
<td>19</td>
<td>0.03</td>
<td>0.07</td>
</tr>
<tr>
<td>20</td>
<td>0.03</td>
<td>0.08</td>
</tr>
<tr>
<td>Total</td>
<td>10.11</td>
<td>15.22</td>
</tr>
</tbody>
</table>

There was no significant difference between the two fertiliser treatments in yield (average 74 tonnes/ha), the amount of nitrogen in the above ground biomass (73 kg N/ha) or the amount of nitrogen exported from the plots (48 kg N/ha). There was, however, a significantly lower surplus (fertiliser nitrogen minus exported nitrogen) with the N_farm treatment having a surplus of 136 kg N/ha and N_repl a surplus of 57 kg N/ha.

**Discussion**

The most important finding in this paper is the confirmation that nitrogen losses from sugarcane to surface water can be reduced by lowering the nitrogen fertiliser application rate. Importantly, in these trials, the nitrogen fertiliser application rate was not too low to negatively impact on cane yield. Losses of total nitrogen to surface water from a sugarcane production system were reduced approximately 33% when fertiliser application rate was reduced from the growers normal rate of 186 kg N/ha to a nitrogen replacement rate of 102 kg N/ha.

The recorded total nitrogen losses to surface water over the 2003/04 wet season were 15 kg/ha when the N_farm application rate was used and 10 kg/ha with the N_repl application rate. These losses of nitrogen to surface water seem to be small (8 to 10% of applied nitrogen), and would not cause any significant agronomic impact, reflecting the findings of Ng Kee Kwong *et al.* (2002), who measured small losses of nitrogen to surface water and described the losses they found as ‘agronomically insignificant’. While this may be so, this contribution of nitrogen from sugarcane production to surface water may be contributing to the degradation of the Great Barrier Reef when
aggregated over the entire Australian sugarcane industry. Given the importance of nitrogen in surface water in Great Barrier Reef catchments, the 33% reductions reported here from lowering the nitrogen application rate could be highly environmentally significant.

There was a 38 day time lag between fertilisation date and the first event, probably allowing sufficient time for the urea fertiliser to hydrolyse and be immobilised into the soil organic matter. The first event did have the highest event mean concentration of total nitrogen, and this concentration reduced through the season.

Walton et al. (2000) investigated using tracer (KBr) losses to determine loss processes from sugarcane (KBr acts in a similar way to nitrate in water). Their study used rainfall simulation equipment, with simulated rainfall applied as soon as practical after tracer application. They reported high losses of the tracer and concluded nitrate losses from sugarcane to surface water could be significant. Comparing the results of Walton et al. (2000) with Ng Kee Kwong et al. (2002) and the results presented here suggests the time lag between fertiliser application and the first runoff event is a major determinant of the total nitrogen loss potential from sugarcane. This is consistent with the review of Daniels et al. (1998), who stated the amount, intensity and timing of the first runoff event after chemical application is the important determinant of losses.

In conclusion, we have shown that lowering N application rates will reduce N losses from sugarcane to the environment. Currently, losses of nitrogen in Great Barrier Reef catchments are too high (Brodie and Mitchell, 2005), and this study shows conclusively lower nitrogen fertiliser application rates will reduce the nitrogen load from sugarcane production systems to the Great Barrier Reef. The nitrogen replacement method (Thorburn et al., 2004) of determining nitrogen application rate is appropriate for determining lower application rates that achieve the dual goals of maintaining yield and benefiting downstream ecosystems.

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L'IMPACT DE DOSES REDUITES D'ENGRAIS D'AZOTE SUR LES TENEURS EN AZOTE DES EAUX DE SURFACE

Par

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MOTS-CLÉS: Substitution d'Azote, Ruissellement, Engrais, Urée.

Résumé

LES PERTES d'azote des systèmes de culture dans l’eau ont potentiellement un impact négatif sur la santé de l’homme et l’écosystème. Les dommages environnementaux sur les récifs de la Grande barrière dus aux apports supplémentaires d'azote consécutif à l’établissement des européens devient de plus en plus apparent. La canne à sucre est culture intensive dominante autour des captages de la grande barrière, et par conséquent les pratiques de gestion azotée de cette industrie sont de plus en plus examinées minutieusement et pressées d’établir des pratiques de gestion azotée qui réduisent les pertes en azote vers l'environnement extérieur. Un essai a été mené en canne à sucre sur la côte tropicale humide de l'Australie afin de déterminer les pertes d'azote vers les eaux de surface causées par deux apports différents d'engrais d'azoté. Les résultats montrent que les diminutions substantielles d’apports d’engrais azoté ont réduit de 34 % les pertes d’azote vers les eaux de surface. Entre 10 et 15 kilogrammes N/ha/an sont perdus par ruissellement, ce qui est agronomiquement insignifiant. Cependant, agrégés au niveau de l'industrie sucrière, ces pertes peuvent être nuisible à la santé de Grande Barrière.La diminution des apports d’azote est une stratégie appropriée qui peut améliorer la qualité de l'eau et entrainer des charges inférieures d'azote vers les écosystèmes en aval.
EL IMPACTO DE LAS DOSIS REDUCIDA DE NITRÓGENO DE FERTILIZANTES EN LOS NIVELES DE NITRÓGENO EN LAS AGUAS SUPERFICIALES

Por

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PALABRAS CLAVE: Sustitución de Nitrógeno, Escorrentía, Abonos, Urea.

Resumen

La pérdida de nitrógeno desde los sistemas agrícolas hacia el agua tiene potencial para impactar negativamente sobre la salud humana y los ecosistemas. Daños ambientales en la Gran barrera de coral como resultado de las aportaciones de nitrógeno extra desde la colonización europea se está convirtiendo cada vez más evidente. La caña de azúcar es el intensivo uso de la tierra dominante en la Gran Barrera de Coral de las cuencas, y en consecuencia de este sector las prácticas de manejo de nitrógeno se encuentran bajo escrutinio cada vez mayor y la presión para implementar prácticas de manejo del nitrógeno, que reducir las pérdidas de nitrógeno al medio ambiente. Se realizó un experimento en la caña de azúcar en la costa tropical húmedo de Australia para medir las pérdidas de nitrógeno a partir de dos tipos diferentes de fertilizantes de nitrógeno a las aguas superficiales. Los resultados muestran que un descenso sustancial en la tasa de aplicación de nitrógeno reducido nitrógeno perdido en las aguas superficiales un 34%. Entre 10 y 15 kg N / ha / año se perdió en las aguas de escorrentía como nitrógeno total, que es insignificante punto de vista agronómico, sino agregados sobre la industria de la caña de azúcar entera, puede ser perjudicial para la salud de la Gran Barrera de Coral. Para la industria de la caña de azúcar para reducir las pérdidas de nitrógeno para mejorar la calidad del agua, la reducción de las tasas de abono es una opción de gestión apropiadas que pueden entregar las contribuciones más bajas de nitrógeno a los ecosistemas aguas abajo.
INFLUENCE OF BIO-ETHANOL DISTILLATION RESIDUE ON WATER QUALITY OF AN UNDERGROUND DAM

By

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KEYWORDS: Bio-ethanol, Sugarcane, Vinasse.

Abstract

BIO-ETHANOL made from sugarcane is considered clean energy since the carbon accumulated in the plant is obtained from the atmosphere so that there is no net CO₂ flux when the biomass-energy is burned. In Okinawa, where the major sugarcane production takes place in Japan, a project for making bio-ethanol from molasses is being conducted. However, wasted liquid, called vinasse, that is 15 times as much as the distilled ethanol, is generated during the distillation, which is certainly a problem when creating sustainable energy. This vinasse is extremely dark brown and contains highly concentrated macro- and micro-nutrient elements, so it could be used as a liquid fertiliser. However, effects of the application of the vinasse on a soil are unknown. In addition, in Miyakojima in Okinawa, where the cultivated land area is limited and depends on an underground dam as a main water source, the sugarcane growers are anxious about the influence of colour especially and nitrate contamination of ground water by applying vinasse to their fields. We examined how the application of vinasse affects the ground water by analysing the drainage through a soil column after the application of 500 mL of vinasse and diluted vinasse over a 29-day period. From the ionic analysis for the nitrate concentration of the drainage of the each column, the potential for nitrate contamination in the underground dam by applying the diluted vinasse is of little concern. By the fact that application of the genuine vinasse caused the highly colored drainage, and with respect to possible salinity, we propose that the amount and times of diluted vinasse application as a fertiliser be limited.

Introduction

Japan imports about 80% of its energy. The Ministry of Economy, Trade and Industry and the Ministry of the Environment in the Japanese Government launched a project for producing bio-ethanol from the materials which do not conflict with food, such as dumped foodstuffs, extra-lumber for architecture and molasses.

The amount of the bio-ethanol made in Japan in 2005–2006 was about 30 kL, and a lot of effort is needed to accomplish the short term goal, 1.5 million kL/year, by 2015.

In Miyakojima Island in Okinawa, the area of sugarcane is around 8400 ha and the total amount of the production of sugarcane is approximately 300 kt.

In this island, producing bio-ethanol from molasses is being worked on as a part of the project. About 6000 t/year of molasses is made, and most of it has been transported to the main island of Japan for use as food for livestock. In the distillation process, ethanol is refined out of the residue, called vinasse.
In Miyakojima Island, at the refinery, 15–20 litres of vinasse for each litre of ethanol are produced, while using conventional technologies, 10–13 litres is produced in Brazil (Rocha et al., 2007). The vinasse in Miyakojima is an extremely dark, brown-coloured liquid, of acid nature, which has highly concentrated chemical components.

Returning vinasse to the farm as a partial or total substitute for mineral nutrients is thought to be a possible solution for disposal of the vinasse (Rocha et al., 2007).

However, since an underground dam supplies domestic water for the people in Miyakojima, sugarcane growers are concerned about the influence of the vinasse on it. In addition, nitrate contamination to the underground dam is also a concern.

The objective of this study is to assess the impact of diluted or non-diluted vinasse application on the groundwater by analysing drainage infiltrated through soil.

For the analysis, a column study was conducted and the turbidity, pH, EC and anions in the drainage were measured.

**Materials and methods**

**Soil sample and vinasse material**

The soil we used in this experiment was located in the experimental field in the University of the Ryukyus. The soil is low alkaline red clay soil and is widely spread in the Okinawa main island and in the other small separated islands, including Miyako Island.

The vinasse from the experimental bio-ethanol producing facility in Miyako Island had been applied to a column study. The vinasse is dark brown colored and, has highly concentrated chemical elements (Table 1).

| Table 1—Chemical properties of the vinasse used in this experiment. |
|-------------|-------|-----|-----|------|-----|-----|-----|-----|
|              | Na    | Mg  | P   | S    | K   | Ca  | Cl  | NO₃⁻ | pH  |
| Vinasse      | 603   | 2709| 180 | 4164 | 23  | 1564| 1082| 0    | 4.1 |

**Column study**

A total of 5 columns were made from polyvinyl chloride (PVC) pipe with inside diameter of 18.2 cm, length of 105 cm and a drain-hole with 1.5 cm diameter at the side 1 cm above the bottom of the column.

The bottom of the column was closed by the square PVC board which allowed the column to stand still. Twenty centimetre length tubes were fixed into the drain-hole, connecting the column and the flask which collects the drainage sample coming through the column.

The column was filled with mixed soil, 4 of 5 columns were saturated with water to compare buffer effects of soil with and without water, which was expected to allow the components of the vinasse to move more freely and remained for 24 hours to let the water drain by gravity.

The depths of the soil in the each column were equal to 96 cm. The photographs of the column just before the application are shown in Figures 1 and 2.

We set up 4 series of vinasse applications with 3 different concentrations of vinasse and 1 control (water) versus saturated soil columns, and a vinasse versus an unsaturated soil column.

Table 2 shows a tested series of column study. The different concentrations of vinasse were: a raw vinasse and diluted vinasse by 10% and 2%, and 500 mL of water poured into the column by hand. Sample-collections and applications were performed every morning. Samples were reserved in the refrigerator at 4°C.
Table 2—Tested series of column study.

<table>
<thead>
<tr>
<th>Column code</th>
<th>Vinasse application</th>
<th>Pre-soil condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rate of dilution(%)</td>
<td>Saturated(+)</td>
</tr>
<tr>
<td>A</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>B</td>
<td>–</td>
<td>+</td>
</tr>
<tr>
<td>C</td>
<td>10</td>
<td>+</td>
</tr>
<tr>
<td>D</td>
<td>2</td>
<td>+</td>
</tr>
<tr>
<td>E</td>
<td>Water (control)</td>
<td>+</td>
</tr>
</tbody>
</table>

Fig. 1—The prepared columns.

Fig. 2—The flask collecting the drainage from a column.

Measurements of the drainage water properties

For each drainage sample, we measured turbidity, pH, EC and anions. Anion contents measured were limited to nitrate, chloride and sulfate among the column c, d and e. pH and electrical conductivity were measured by turbidity sensor, pH sensor and EC meter respectively.

For the determination of anion contents in the drainage sample, each sample was filtrated through a membrane filter with a 5 mL plastic syringe to a vial of 500 µL volume and measured by ion chromatography.

The drainage of Column A was dripped for the first time at the 16th application (8 litre), while the other columns were obtained from the beginning of the application.

Results

The chemical properties of the drainage from the each column are shown in Figure 3. In each analysis, there was little variation detected up to the 15th application. After that point, the turbidity and EC of the drainage from columns A and B (applications of genuine vinasse) drastically escalated with each additional application. However, the drainage from columns C and D showed no change in turbidity and less increase in EC than for the raw vinasse.

Only when raw vinasse was applied was there a drop in pH of the drainage to approximately 6.5. In columns C, D and E, nitrate and sulfate concentrations in the drainage showed little fluctuation, and the highest density was found in Column E followed by D, then C at the 29th application. On the other hand, the chloride concentration in the drainage from columns C and D increased although the latter showed only a little gain (Figure 4).
Fig. 3—Chemical analysis of the drainage collected from 5 columns, each alphabets (A, B, C, D, and E) correlates with column codes in Table 2.

Fig. 4.—Anion analysis of the drainage from 3 columns (C, D and E).
Discussion

Effects on ground water quality

Though the present study gives the extreme results of unusual day-to-day applications of vinasse as a fertiliser, only applying the raw vinasse to the soil has the potential to cause observable effects on the turbidity and pH of the underground water.

Besides, by applying the raw vinasse to an unsaturated column continuously, both electric conductivity and pH reached the same levels as the application of the raw vinasse to a saturated column. It suggests that whether soil is wet or not, applying the raw vinasse has a potential to contaminate the underground dam once it reaches the limitation of soil capacity as a buffer.

However, considering the depth of the soil layer down to the underground dam, the fact that it took 16 applications (8 litres equivalent to 308 mm) for the raw vinasse to infiltrate the unsaturated soil thoroughly is an important consideration.

Application of a limited amount or times of a diluted vinasse may not directly affect the turbidity or pH of the underground dam. Since an increase of nitrate and sulfate ions in the drainage was not detected, the contamination of nitrate to the underground dam is of less concern.

However, the constant applications of vinasse on the soil increased the electric conductivity of the drainage, which suggests possible inhibition of the growth of crops by the application of vinasse.

The concentration of chloride and EC are highly correlated \((r = 0.94)\) and when the 10% diluted vinasse was applied continually, the concentration of chloride reached more than 1200 mg/L at the 29th application.

Consequently, salinity should be considered when determining how much the vinasse should be diluted and how many times it should be applied as a fertiliser.

REFERENCES

INFLUENCE DES RESIDUS DE LA DISTILLATION DE BIO-ETHANOL SUR LA QUALITE DE L’EAU D’UN BARRAGE SOUTERRAIN

Par

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KEYWORDS: Bio-ethanol, Sugarcane, Vinasse.

Résumé

Le bio-éthanol fabriqué à partir de la canne est considéré comme une énergie propre puisque le carbone accumulé dans la plante est obtenu à partir de l’atmosphère de telle sorte qu’il n’y a pas de flux net de CO2 quand la biomasse-énergie est brûlée. A Okinawa, zone principale de production de canne à sucre au Japon, un projet de fabrication de bio-éthanol à partir des mélasses a été réalisé. Cependant, un déchet liquide appelé vinasse, 15 fois plus important en quantité que le bio-éthanol, est généré pendant la distillation, ce qui entraîne un problème environnemental lors de la création d’énergie durable. Cette vinasse brun foncé, est fortement concentrée en micro et macro éléments et pourrait être utilisée comme engrais liquide. Cependant, les effets de l’application des vinasses sur le sol ne sont pas connus. De plus, à Miyakojima (Okinawa), où la surface en terre cultivable est limitée et dépend d’un barrage souterrain comme principale ressource en eau, les planteurs de canne sont inquiets à propos de la coloration et de la contamination en nitrates de la nappe phréatique après application de vinasse dans les champs. Ainsi, nous avons étudié comment l’application de vinasse affecte la nappe phréatique en analysant le drainage à travers une colonne de sol après application de 500 ml de vinasse pure et de vinasse diluée pendant 29 jours. A partir des analyses de concentrations en nitrates des eaux drainées de chaque colonne, le potentiel de contamination en nitrates dans le barrage souterrain en appliquant de la vinasse diluée est un problème mineur. Du fait que l’application de vinasse entraîne un drainage fortement coloré et une possible salinité, nous proposons que les quantités et fréquences d’apports de vinasse diluée comme engrais soient limitées.
INFLUENCIA DEL RESIDUO DE LA DESTILACIÓN DE BIOETANOL EN LA CALIDAD DEL AGUA DE LA PRESA SUBTERRÁNEA

Por

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PALABRAS CLAVE: Bioetanol, Caña de Azúcar, Vinaza.

Resumen
EL BIOETANOL producido de caña de azúcar es considerado como energía limpia, dado que el carbón acumulado en la planta se obtiene de la atmósfera, de tal manera que no hay flujo neto de CO₂ cuando se consume la energía de la biomasa. En Okinawa, donde se produce la mayor parte de la caña de azúcar en Japón, se efectúa un proyecto para producir bioetanol a partir de melaza. Sin embargo, de esto se genera el residuo líquido denominado vinaza, cuyo volumen es 15 veces más que el del etanol destilado, lo cual representa un problema en la producción de energía sostenible. La vinaza posee un color marrón muy oscuro y contiene altas concentraciones de macro y micronutrientes, por lo que puede utilizarse como fertilizante líquido. No obstante, los efectos de la aplicación de la vinaza sobre el suelo se desconocen. Además, en Miyakojima, Okinawa, donde el área para cultivo es limitada y depende de la presa subterránea como principal fuente de agua, los productores están preocupados por la influencia que tengan, especialmente el color y contaminación con nitrato en el agua subterránea, por la aplicación de vinaza en sus campos. En el presente trabajo se examinó cómo la aplicación de vinaza afecta el agua subterránea, por medio del análisis del drenaje a través de una columna de suelo, después de la aplicación de 500 ml de vinaza y vinaza diluida, por un período de 29 días. Del análisis iónico para determinar la concentración de nitrato del drenaje de cada columna, muestra que el potencial de la contaminación con nitrato de la presa subterránea es de poca importancia cuando se aplica vinaza diluida. Dado que la aplicación de la vinaza sin diluir provoca una coloración fuerte en el drenaje y, posiblemente salinidad, se propone que se limite la cantidad y frecuencia de aplicación de vinaza diluida como fertilizante.
UTILISATION OF SILICON FROM METALLURGY SLAG BY SUGARCANE

By

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KEYWORDS: Silicate, Soluble Si, Silicon Recovery, Accumulated Si.

Abstract
SUGARCANE is a species that accumulates silicon (Si) and has the ability to respond to silicon fertilisation, especially in soils where this element is scarce. Metallurgy slags constitute a source of Si in soils where this crop is grown. The objective of this paper was to study the value of metallurgy slag as a source of Si for sugarcane. A randomised block experimental design was adopted, in a 2×4 factorial combination represented by two sugarcane cultivars (SP81-3250 and RB86-7515) and four Si rates of slag providing 0, 100, 200, and 400 kg/ha. The application of metallurgy slag (silicate) increased the available soil Si content as well as the status of available Si and the Si content in sugarcane leaves. The amount of Si from the applied silicate accumulated by the above-ground part of sugarcane ranged between 23 and 56% in varieties RB86-7515 and SP81-3250, respectively. On average, 39% of the Si absorbed by the above-ground part of sugarcane came from the applied fertiliser (silicate).

Introduction
At present, the importance of sugarcane has been highlighted as a source material for the production of sugar and more particularly because it constitutes a basic input for the production of ethanol. Brazil stands out in the world scenario as the largest producer of sugarcane (Brazil. Ministério da Agricultura e Pecuária, 2007). However, many sugarcane areas in the country are characterised by significantly weathered soils, and therefore have small amounts of soluble or available silicon (Si) available to crops.

Sugarcane is considered a Si-accumulating crop. Several studies (Pereira et al., 2004; Carvalho-Pupatto et al., 2003; Berni and Prabhu, 2003) have demonstrated that grasses respond favourably to silicon fertilisation, especially when grown in soils deficient in ‘available’ Si.

Si provides many benefits to sugarcane including increased photosynthetic efficiency and resistance to the attack of pests and diseases, higher tolerance to water stress during periods of low soil moisture (Korndörfer and Datnoff, 1995), relief from damage caused by frosts and improved plant architecture (Savant et al., 1999), among others.

Such benefits result in improved sugarcane quality and increased sugarcane productivity. According to Kingston et al. (2005), the beneficial effects of Si in sugarcane clearly indicate that this element should be treated as an integral part of the fertilisation practices associated with sugarcane cultivation.

The metallurgy slags from iron steel production are basically composed of calcium and magnesium silicates. So long as they do not contain heavy metals in their composition, they can satisfactorily meet the requirements of a good Si source for agricultural use, such as: high soluble Si content, easy mechanised application, balanced ratios and amounts of calcium (Ca) and magnesium (Mg), low cost, and low soil contamination potential with heavy metals (Korndorfer et al., 2004a).
Although the agricultural use of industrial residues such as metallurgy slags is not very common in Brazil in spite of the high quantities available, their use as a source of Si for plants has been studied and in many parts of the world (Prado and Fernandes, 2001).

Considering that part of Si absorbed/accumulated by plants comes from the soil and another part comes from Si applied in the form of fertiliser, our aim in this study was to evaluate varietal differences with regard to Si absorption and the amount of accumulated Si in the above-ground part that is derived from metallurgy slag.

**Material and methods**

The experiment was conducted in an experimental area of Universidade Federal de Uberlândia, in Uberlândia city, Brazil, simulating a field situation, during the period from August 15, 2007 to May 2, 2008.

A randomised block experimental design was adopted, in a 2×4 factorial combination represented by two sugarcane cultivars (SP81-3250 and RB86-7515) and four rates of Si (0, 100, 200, and 400 kg/ha), with four replicates (Table 1).

The metallurgy slag (CaSiO$_3$) employed had the following physical and chemical characteristics: powder formulation, CaO: 42%, MgO: 12%, SiO$_2$: 23%, total Si 11.2% (determined by colorimetry after extraction with hydrochloric acid and hydrofluoric acid, according to methodology described by Korndorfer et al (2004b), P$_2$O$_5$: 0.4%, K$_2$O: 0.2%, SO$_4$: 4.4%, Fe: 8.5%, Mn: 1.4%, Mo: 0.4 mg/kg; and Zn: 0.1 mg/kg. Each experimental plot consisted of a plastic tank (200 L capacity), filled with 200 kg of soil where three sugarcane stools were planted.

The soil used in the pots was taken from the 0–20cm of a soil classified as typic Dark Red Dystrophic Latosol with the following chemical characteristics: organic matter = 13 g/dm; pH in CaCl$_2$ 0.01 mol/L (1:2.5) = 5.2; P mehlich = 2.7 mg/dm; K = 1; Ca = 7.0; Mg = 3.0; H + Al = 31.0 all exchangeable in mmol/dm; and V (base saturation) = 27%, (Embrapa, 1999). The amount of soil soluble Si, 4.3 mg/dm, was determined according to a methodology described by Korndorfer et al (2004b), using CaCl$_2$ 0.01 mol/L as extractant.

Before the sugarcane seedlings were transplanted to the tanks (permanent site), pre-established quantities of limestone were applied (Table 1), with physical and chemical characteristics similar to those found in the slag used (TNP 85%, CaO = 42%, and MgO = 12%). Both Ca and Mg were balanced, that is, all pots received identical quantities of Ca and Mg.

All treatments received 100 kg N/ha as ammonium sulfate, 300 kg P$_2$O$_5$/ha as single superphosphate, 300 kg K$_2$O/ha as potassium chloride, 80 kg/ha of a cocktail (FTE – BR12) containing 9% Zn, 1.8% B, 2% Mn, 0.8% Cu, 0.1% Mo, and 3% Fe, as recommended by Boletim Técnico N° 100 (1996).

**Table 1**—Treatments and amount of slag and lime used in the experiment.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Slag rates</th>
<th>Lime rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 0 kg/ha of Si, cultivar RB86-7515</td>
<td>0</td>
<td>3559</td>
</tr>
<tr>
<td>2. 100 kg/ha of Si, cultivar RB86-7515</td>
<td>890</td>
<td>2669</td>
</tr>
<tr>
<td>3. 200 kg/ha of Si, cultivar RB86-7515</td>
<td>1779</td>
<td>1779</td>
</tr>
<tr>
<td>4. 400 kg/ha of Si, cultivar RB86-7515</td>
<td>3559</td>
<td>0</td>
</tr>
<tr>
<td>5. 0 kg/ha of Si, cultivar SP81-3250</td>
<td>0</td>
<td>3559</td>
</tr>
<tr>
<td>6. 100 kg/ha of Si, cultivar SP81-3250</td>
<td>890</td>
<td>2669</td>
</tr>
<tr>
<td>7. 200 kg/ha of Si, cultivar SP81-3250</td>
<td>1779</td>
<td>1779</td>
</tr>
<tr>
<td>8. 400 kg/ha of Si, cultivar SP81-3250</td>
<td>3559</td>
<td>0</td>
</tr>
</tbody>
</table>

The amount of soil used in each tank was divided into two portions of 100 kg each. The nutrients (both macro and micro) were incorporated in to one of those parts. Next, the soil was placed in the bottom of the tank. The treatments, the limestone and the slag were incorporated into
the second portion of soil, which was then placed in the pot, over the first portion. This procedure was adopted to achieve a uniform distribution of nutrients in the entire tank, leaving the limestone and the silicate in the first soil layer only. Water was added in the next step, with about 32 L applied per pot; this is the quantity required to reach approximately 70% of field capacity. The amounts of slag and limestone used in each treatment are presented in Table 1.

Three pre-germinated (one month old) cuttings of sugarcane were planted in each tank on September 13. Two kg/ha boric acid were applied per pot on December 10, 2007 (87 days after transplanting). On December 17, 2007, after nitrogen deficiency was detected, we applied 200 kg/ha N in the form of ammonium sulfate (20% N). On December 21, 2007 we again applied 2 kg/ha boric acid. Leaves (first leaf from the apex to the base at the TVD or Top Visible Dewlap) were collected in January 2008 for Si analysis according to methodology described by Korndorfer and Ramos (2008). Soil samples were taken on the same day for determination of available or soluble Si.

Since a high infestation of sugarcane spittlebugs was observed in the overall experiment, the insecticide thiamethoxan 250WG was applied on March 13, 2008 at a rate of 2.5g of active ingredient per 4 L water. The sugarcane was harvested eight months after planting. At harvest, the plants were divided into leader shoot (heart + leaves) and stalks and then weighed.

The plant material was ground separately and dried in a forced air circulation oven at 65°C to constant weight. After drying, the material was placed in properly identified plastic bags. Si accumulation by the plants was determined as a function of dry matter yield and on Si content in the tissues of the various plant parts.

Si determinations were made according to analytical procedures described by Korndorfer et al. (2004a). After harvest, soil samples were taken from each pot for determination of soluble Si analysis according to Korndorfer et al. (2004a) and for determination of pH and exchangeable Ca and Mg analysis according to Embrapa (1999). The qualitative results were submitted to analysis of variance and means were compared using Tukey’s test at 5% significance. The quantitative results were submitted to polynomial regression analysis. The SISVAR software was used in the statistical analysis (Ferreira, 2000).

**Results and discussion**

Si content in the soil showed an increasing trend with increasing rates of slag at 120 and 260 days after application (Figure 1).

![Graph showing the relationship between Si content and Si rates](image)

The data showed that, at 120 days, indicated Si content increased by 18, 56, and 72% relative to the control, for doses of 100, 200, and 400 kg Si/ha, respectively. At 260 days, soil Si contents in the treatments that received 100, 200, and 400 kg/ha Si were 2, 8, and 50% higher than the control, indicating that nine months after application, the slag continued to supply Si to the soil although at smaller quantities with the lower rates of 100 and 200 kg Si/ha.
By comparing the soil Si results at 120 and 260 days after slag application, a significant reduction can be noted in available Si contents in the soil (Figure 1). Such difference can be explained in part by Si extraction by the sugarcane (Table 2). Si contents in the plants increased from 12.31 to 17.46 g per pot when the Si dose applied was 400 kg/ha, corresponding to an increase of approximately 70% in the amount of Si extracted by the above-ground part of sugarcane (Table 2).

The increased Si contents in the soil caused by the application of slag resulted in increased amounts of Si accumulated in the above-ground part of sugarcane (Table 2).

The silicon mean recovery from slag (mean of two sugarcane cultivars) was 39.4%, varying from 25.8 to 56.6% depending on the Si rate used (Table 2). Considering the fact that the soil under study had low clay (sandy soil), low organic matter and low water retention capacity, the interaction of the slag particles with the soil solid phase was smaller, which can explain the low reactivity of the slag (silicate) applied. This result agrees with those reported by Korndörfer et al. (1999), who studied the effect of calcium silicate as a source of Si on upland rice crop in four soils representative of the savanna region and found greater recovery of this element in soils with higher clay contents.

### Table 2—Soil available Si, Si accumulated in the above-ground part of plant, Si uptake from the fertiliser, and Recovery Index as a function of Si doses applied (mean of 2 varieties).

<table>
<thead>
<tr>
<th>Si applied (g per pot)</th>
<th>Soil available Si</th>
<th>Si accumulated above-ground part of the plant</th>
<th>Si uptake from the fertiliser*</th>
<th>Recovery index**</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.42</td>
<td>12.31</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>5</td>
<td>0.43</td>
<td>15.14</td>
<td>2.83</td>
<td>56.6</td>
<td>39.4</td>
</tr>
<tr>
<td>10</td>
<td>0.45</td>
<td>15.89</td>
<td>3.8</td>
<td>35.8</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>0.63</td>
<td>17.46</td>
<td>5.15</td>
<td>25.8</td>
<td></td>
</tr>
</tbody>
</table>

* Absorbed Si from the fertiliser = Si accumulated in the above-ground part – Si accumulated by the control;
** Recovery Index (%) = (absorbed Si from the fertiliser/applied Si) × 100

Cultivar SP81-3250 had the highest Si recovery capacity (Recovery Index equal to 55.8%), which means that of all absorbed Si more than one half came from the fertiliser. The difference between recovered Si amounts was approximately 60%, which gives variety SP81-3250 a greater capacity of utilising Si from the fertiliser (slag) when compared with variety RB86-7515 (Figure 2).
In general, cultivar SP81-3250 proved superior to RB86-7515 for its capacity to accumulate Si in the top leaves, lower leaves, and stalks, which resulted in greater accumulation of this element in the whole above-ground part of the plant (Table 3).

The mean contents of Si accumulated in the top leaves, lower leaves, stalks, and the whole above-ground part of cultivar SP81-3250 were 80%, 29%, 23%, and 24% higher, respectively, than the values accumulated by variety RB86-7515 (Table 3).

The mean Si contents accumulated in the leaves, stalk, and the whole above-ground part increased linearly with Si doses applied (Figures 3a, 3b, and 3c).

This fact reinforces the importance of Si use in sugarcane fertilisation to obtain greater resistance against pests, diseases and drought susceptibility.

The foliar diagnosis performed at 87 days after planting the seedlings showed that variety RB86-7515 had a higher incidence of B deficiency symptoms when compared with variety SP81-3250 (Table 4).

Table 3—Effect of slag on accumulation of Si in different plant parts in two sugarcane cultivars.

<table>
<thead>
<tr>
<th>Si rates kg/ha</th>
<th>Si accumulated top leaves g/pot</th>
<th>Si accumulated lower leaves g/pot</th>
<th>Si accumulated stalks g/pot</th>
<th>Si accumulated above-ground part g/pot</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SP81-3250</td>
<td>RB86-7515</td>
<td>SP81-3250</td>
<td>RB86-7515</td>
</tr>
<tr>
<td>0</td>
<td>2.49 a</td>
<td>1.20 b</td>
<td>8.62 a</td>
<td>7.76 a</td>
</tr>
<tr>
<td>100</td>
<td>2.59 a</td>
<td>1.30 b</td>
<td>12.01 a</td>
<td>8.06 b</td>
</tr>
<tr>
<td>200</td>
<td>2.28 a</td>
<td>1.57 b</td>
<td>13.00 a</td>
<td>8.90 b</td>
</tr>
<tr>
<td>400</td>
<td>2.75 a</td>
<td>1.47 b</td>
<td>11.84 a</td>
<td>11.63 a</td>
</tr>
<tr>
<td>Average</td>
<td>2.53 a</td>
<td>1.39 b</td>
<td>11.37 a</td>
<td>9.09 b</td>
</tr>
</tbody>
</table>

CV: 20% LSD (cultivar): 0.59 LSD (mean): 0.29

Table 4—Effect of slag on Si content in different plant parts and number of leaves with B deficiency in two sugarcane cultivars.

<table>
<thead>
<tr>
<th>Si rates kg/ha</th>
<th>Si content top leaves %</th>
<th>Si content lower leaves %</th>
<th>Si content stalks %</th>
<th>Number of leaves B deficiency***</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SP81-3250</td>
<td>RB86-7515</td>
<td>SP81-3250</td>
<td>RB86-7515</td>
</tr>
<tr>
<td>0</td>
<td>0.32 a</td>
<td>0.33 a</td>
<td>0.93 a</td>
<td>0.96 a</td>
</tr>
<tr>
<td>100</td>
<td>0.34 a</td>
<td>0.33 a</td>
<td>1.16 a</td>
<td>0.92 a</td>
</tr>
<tr>
<td>200</td>
<td>0.36 a</td>
<td>0.35 a</td>
<td>1.22 a</td>
<td>0.98 a</td>
</tr>
<tr>
<td>400</td>
<td>0.37 a</td>
<td>0.37 a</td>
<td>1.21 a</td>
<td>1.35 a</td>
</tr>
<tr>
<td>Average</td>
<td>0.35 a</td>
<td>0.35 a</td>
<td>1.13 a</td>
<td>1.05 a</td>
</tr>
</tbody>
</table>

CV: 10% LSD (cultivar): 0.05 LSD (mean): 0.03

*Means followed by the same letter in the line are not significant by the Tukey test at 5% significance.
***LSD = least significant difference.

**Means followed by the same letter in the line are not significant by the Tukey test at 5% significance.
****LSD = least significant difference.

*** Report made 87 days after seed transplanting.
The two sugarcane cultivars did not differ from each other for Si content in the top leaves and lower leaves in any of the doses applied (Table 4). However, the mean Si concentrations increased from 0.33 to 0.37% in the top leaves and from 0.94% to 1.28% with the highest rate of 400 kg/ha.

Regardless of cultivars, Si concentration in the top leaves and the lower leaves increased linearly with doses of this element (Figures 4a and 4b). When the control is compared against the highest Si dose (400 kg/ha), the mean values of increase in Si concentration in the top leaves and lower leaves were 36 and 12%, respectively.

Variety SP81-3250 had a significantly higher (14% higher, on average) Si content in stalks compared to variety RB86-7515 (Table 4). Considering only the two highest Si doses (200 and 400 kg/ha), cultivar SP81-3250 concentrated 15 and 22% more Si in stalks, respectively, than RB86-7515 (Table 4).

Silicon deposition in stalks may increase sugarcane resistance to lodging (Ma and Takahashi, 2002). This trait is particularly important in mechanised green cane harvest. The selection of varieties with high Si uptake potential could minimise damping-off problems in mechanised harvest.

The mean Si content in stalks of both sugarcane varieties increased linearly with Si doses applied to the soil (Figure 4c). Plants grown in the presence of 400 kg/ha Si had 60% more Si in stalks than control plants.
Si deposition in stalks could also increase sugarcane resistance to the attack of pests such as the stalk borer, *Eldana saccharina* (Lepidoptera: Piralidae) (Keeping and Meyer, 2005).

**Conclusions**

a) The silicate application increased the soil content of available Si and the Si content in sugarcane leaves.

b) The amount of Si from the applied silicate accumulated by the above-ground part of sugarcane ranged between 23 and 56% in varieties SP81-3250 and RB86-7515, respectively.

c) On average, 39% of the Si absorbed by the above-ground part of sugarcane came from the applied fertiliser (silicate).

**Acknowledgments**

This work was supported by collaborative projects funded by FAPEMIG and CNPq. The authors would like to thank Mr Eduardo Junqueira Motta Luiz for the pots donation and also Dr. Lísias Coelho for the assistance in many aspects of the work.

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UTILISATION PAR LA CANNE À SUCRE DU SILICIUM PROVENANT DE SCORIES DE METALLURGIE

Par

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MOTS-CLÉS: Silicate, Si soluble, Contribution du Silicium, Silicium Accumulé.

Résumé

LA CANNE à sucre est une espèce qui accumule le Silicium (Si) et a la capacité de répondre à de la fertilisation à base de Silicium, spécialement dans les sols où cet élément est rare. Les scories de métallurgie constituent une source de Si pour les sols où la canne à sucre est cultivée. L’objectif de ce papier est d’étudier la valeur des scories de métallurgie comme source de Si pour la canne à sucre. Un essai factoriel 2×4 en blocs randomisés fut réalisé. Cet essai comprenait 2 variétés (SP81-3250 et RB86-7515) et 4 doses (0, 100, 200, et 400 kg/ha) de Si provenant de scories. L’épandage des scories de métallurgie (silicate) augmenta la teneur en Si assimilable du sol aussi bien que le statut en Si assimilable et la teneur en en Si des feuilles. La quantité de Si accumulée par les parties aériennes de la canne à sucre variait respectivement de 23 à 56% dans les variétés RB86-7515 et SP81-3250. En moyenne, 39% du Si absorbé par les parties aériennes provenait de l’engrais appliqué (silicate).

UTILIZACIÓN DE SILICIO PROVENIENTE DEL DESECHO DE LA METALURGIA, POR LA CAÑA DE AZÚCAR

Por

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PALABRAS CLAVE: Silicato, Si soluble, Recuperación de Silicio, Si Acumulado.

Resumen

LA CAÑA de azúcar es una especie que acumula silicio (Si) y tiene la habilidad de responder a la fertilización con silicio, especialmente en suelos donde este elemento es escaso. Los desechos de la metalurgia constituyen una fuente de Si en suelos donde se planta este cultivo. El objetivo de este trabajo era estudiar el valor del desecho de la metalurgia como fuente de Si para la caña de azúcar. Se empleó un diseño experimental de bloques al azar, en una combinación factorial 2×4, representada por dos variedades de caña de azúcar (SP81-3250 y RB86-7515) y cuatro dosis de Si proveniente del desecho, que proporcionaran 0, 100, 200 y 400 kg/ha. La aplicación del desecho de la metalurgia (silicato) incrementó el contenido de Si disponible en el suelo, así como el estado de disponibilidad de Si y el contenido de Si en las hojas de la caña de azúcar. La cantidad de Si del silicato aplicado acumulada en la parte aérea de la planta osciló entre 23 y 56% en las variedades SP81-3250 y RB86-7515, respectivamente. En promedio, 39% del Si absorbido por la parte aérea de la planta provinio del fertilizante aplicado (silicato).
SUGAR PRODUCTION: INTEGRATION AMONG SUGAR, ALCOHOL, RESIDUE CYCLING AND SUSTAINABILITY—A REPORT ON THE 2009 AGRONOMY WORKSHOP

By

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KEYWORDS: Productivity, Trash Management, Green Manuring, Irrigation, Fertilisation, Weed Control.

Abstract

The 2009 Agronomy Workshop was held from 24 to 28 May 2009 in Uberlandia, Brazil. It was attended by some 70 participants with 22 of them travelling overseas from 13 different countries. The workshop was a success with 33 oral presentations (and 16 posters) spread under the following five specific themes: new technologies for sustainable sugar cane production, ratoon yield decline and its management, modelling sugarcane growth and production, soil and plant residue management, and the challenge of environmental pressure and strategy for the sugarcane grower. The workshop was also an opportunity to gain an insight into the sugar industry in Brazil, in particular the cultural practices adopted and the status of research and development in the country. The workshop has served as a reminder to technologists that optimising sugarcane production requires high quality seed to establish the plantation and the adoption of an integrated approach to the management of the crop. This integrated approach to optimise or enhance productivity includes the adoption of the most suitable technology in irrigation, fertilisation, weed management and crop protection. Though it is accepted that a sustainable sugarcane production system lies in soil organic matter conservation, particularly through green-cane harvesting, the management of the residues to avoid loss in productivity still needs to be researched. There will be no universally applicable residue-management system, and each system will need to be tested under the specific conditions prevailing locally. With the rising demand for higher fibre cultivars for cogeneration and ethanol synthesis, research and development in sugarcane agronomy will be increasingly focussed towards optimising the partitioning of the biomass in favour of fibre. The workshop has also created awareness that research and development initiatives will not attain the objective of enhanced productivity if social and organisational constraints impacting negatively on agronomic practices at field level are not addressed.

Introduction

The 2009 ISSCT Agronomy Workshop was held from 24 to 28 May 2009 at the Plaza Convention Centre in Uberlandia, Brazil. The workshop was very well organised with three institutions collaborating closely (the Federal University of Uberlandia, the Society of Sugar Cane Technologists of Brazil and APTA) to make the attendance worthwhile and interesting to the participants. However, with the world economy in recession, the response by sugarcane technologists to the workshop was understandably below expectation as, of the 70 participants, only 22 of them were from overseas from 13 different countries.

The workshop nevertheless was an excellent opportunity for the participants from overseas to acquire an overview of the sugar industry in Brazil, in particular the cultural practices and the status of research and development in the country. The constraints to the sugar industry worldwide
at the beginning of this 21st century are wide ranging and, in agronomy, they tend to be the same in all countries. Those constraints to the viability and sustainability of the sugarcane production systems cannot be resolved by research and development in just one specific discipline in agronomy. Instead an integrated approach is warranted and accordingly the theme of the workshop *Sugar production: Integration among sugar, alcohol, residue cycling and sustainability* was chosen to cover the spectrum of interests in agronomy.

Following the opening of the workshop by the Mayor of the City of Uberlandia and a very enlightening keynote address on ‘*Perspective for the sugar cane production in Brazil and in the world*’ by Dr Roberto Rodrigues, a former Minister of Agriculture of Brazil, the scene for discussion and interaction among the technologists was set by 33 oral presentations (and 16 posters) spread under the five following specific themes.

- New technologies for sustainable sugarcane production.
- Ratoon yield decline and its management.
- Modelling sugarcane growth and production.
- Soil and plant residue management.
- Challenge of environmental pressure and strategy for the sugarcane grower.

The discussion after each presentation was positive and lively, demonstrating the interest and willingness of the participants to share and exchange their know-how. A report on the presentations and discussions is given in the sections below.

Report and discussion

**Optimum sugar cane productivity**

One factor that is often overlooked and yet is the basis of a successful sugarcane crop is the necessity for high quality seed cane, particularly free from diseases. Attention to the central role which high quality seed cane plays in reducing costs and bringing out the real productive potential of sugarcane varieties grown was demonstrated in Tucuman, Argentina. Here one of the constraints to sugarcane production was the lack of nurseries guaranteeing high quality seed cane availability and purity, with the result that commercial plantations have widespread high RSD incidence levels (>50%) which may cause production losses of 50%. It also emerged from the workshop that once high quality seed is planted, an integrated approach to the management of the sugarcane crop must be adopted to optimise productivity. In this context, work in Thailand showed that while dual-row planting raised cane yields by 26–31% in plant cane and by 12–24% in first ratoon, dual-row planting with green manuring increased cane yields by 47–48%, while irrigation with recommended fertiliser and dual-row planting caused cane yields to rise by as much as 64–72% without the quality of the cane juice being affected.

It was also evident that to optimise productivity, the most appropriate technology or agronomic management system must be chosen. Thus, though many different irrigation systems are available and can be adopted, work done in Brazil demonstrates that drip irrigation conserves water and energy, thereby further increasing the profitability of the sugarcane production system particularly when varieties showing a better yield potential under the drip irrigation system are grown. The results obtained in Brazil showed a rise in sugarcane production of some 30 tonnes cane per hectare under drip irrigation, with different responses being obtained among the varieties tested.

Further avenues to optimise the profitability and sustainability of the sugarcane production systems that were presented at the workshop were:

- **Use of a foliar biofertiliser consisting of mesophilic, cellulolytic, ammonifying and nitrifying fungi and yeasts and containing low quantities of NPKCa and micronutrients.** Studies in Argentina showed that 10 L/ha of this foliar biofertiliser was an effective substitute for half the dose of N traditionally supplied by synthetic sources, that is 120 kg N/ha as urea instead of 240 kg/ha.
Adoption of leguminous green manure not only to provide nitrogen to the crop but also to improve the fertility of the soil by gradually increasing the organic matter content in the soil and to hinder the development of the weed population. Work in Brazil showed that sunhemp decreased the incidence of light and thermal amplitude on the ground, thereby hindering the germination of weeds. In field trials, while the control without green manure gave cane yields of 135.5 t/ha, treatments with pigeon pea and *Crotalaria juncea* produced 158.8 and 157.0 t cane/ha, respectively. Studies of different rotation systems with leguminous crops in Brazil further showed that the best rotation system for sugarcane in that country was a two-year soybean cultivation as opposed to fallow, one-year soybean cultivation and one or two years with *Crotalaria*.

Adoption of a weed management strategy based on the critical period of competition between weeds and sugarcane. Weed control in sugarcane in Mauritius has traditionally been achieved by two or even three herbicide applications per cropping season and is often complemented by manual weeding. With the adoption of a new strategy based on the initial period of weed control which started at least 6 weeks after planting or harvest and which ended 14–20 weeks later, there was a saving of at least one herbicide application per season. Further savings in herbicide costs were achieved by adoption of mechanical weeding during the first 12–16 weeks after planting and in ratoon by promoting the adoption of green-cane trash blanketing.

Controlling prevalence of pests. Harvest age has been presented as being critical to production of sugarcane in South Africa, a 12, 18 or 24 month cycle being practised depending on the environment. Data were presented to show that lower yields were obtained for the 18-month cane as a result of *Eldana* damage associated with aging of the sugarcane along the coast. High yields with aging cane can only be achieved by planting appropriate varieties that have good *Eldana* resistance. In the control of pests, the merit of silicon to induce sugarcane resistance to insects such as spittlebugs was demonstrated in Brazil.

Management of trash residues

It was clear at the workshop that soil organic matter conservation and build up in the soil are most critical for a sustainable sugarcane production. Data presented from Argentina showed that a trash-blanket treatment led to a significantly higher crop yield (83.5 tonnes cane/ha) as compared with a treatment without residue retention (53.7 tonnes/ha). It was, however, also evident from the presentations and discussion at the workshop that one system of trash-residue management could not fit all situations. The management of the residues from green-cane harvesting still needs to be researched and tested under specific local conditions to avoid drawbacks such as prevalence of pests like the spittlebug, or slower shoot appearance and lower tillering rate as a result of lower temperature under the trash blanket causing ultimately a reduced sugarcane yield as was observed for instance in Brazil. It was reported that a 100% trash cover of the soil gave for instance 83 tonnes cane/ha as opposed to 91 tonnes/ha and 96 tonnes/ha in trash management systems covering respectively, 66% and 33% of the soil surface. Under the temperate climatic conditions of Louisiana, burning the trash as soon as possible after harvest was even shown to give consistently better yields than when the mulch was left on the field after harvest or mechanically removed by a hay bailer.

New technologies

The workshop was an opportunity to present progress or refinements in new technologies that can be applied in sugarcane agronomic management systems. Biomass estimates inferred from remote sensing techniques were shown to be well correlated with gross cane yields obtained from field measurements in Louisiana. The yield variations within field were sufficiently large to justify a precision agriculture approach in the management of the crop. In this context, the suitability of mapping soil pH and electrical conductivity in a 25–ha fallow sugarcane field to assist producers in developing lime variable rate application in sugarcane was demonstrated. Progress in modelling sugarcane growth has been achieved with an up-to-date Canegro model modularised and
incorporated into the DSSAT4.5. Though room for improvement exists, the model was shown to perform fairly well when simulations were compared with experimental data.

In the investigation of the sugarcane root system, particularly root length density which, though a key factor for sugarcane water and nutrient uptake, is difficult to measure, a technique was presented based on root intersection counting with a 0.5 m x 0.5 m mesh grid on a soil profile and modelling the root length density from the root intersection counting. This new method is 10-fold, less time consuming than the core sampling method and has the merit of not needing the export of soil samples. Using the technique developed, studies in Brazil have provided evidence that sugarcane root development in ratoon is not affected by the changes in soil management practices, namely from conventional tillage (soil cultivation and disking twice at planting) to minimum tillage (soil cultivation with one disking at planting) and to no tillage (only disking at planting).

**Initiatives required**

The workshop in Brazil moreover has the merit of drawing attention to the need for broadening the research base in the agronomy of sugarcane. Current research on sugarcane is focused on contemporary cultivars which are designed to have low to moderate fibre levels and high sucrose and fermentables for sugar or ethanol production. A shift in paradigm is now occurring with the higher demand for high fibre cultivars for electricity cogeneration or for conversion of cellulose and hemicellulose to ethanol and syngas. The impact which this shift in paradigm has on biomass partitioning in sugarcane will need to be studied from all angles in agronomy. Preliminary results from Australia showed that, though cultivars did not generally result in significant difference in total biomass production or in the yield of the vegetative components, significant differences, however, occurred among the cultivars in the partitioning of the dry matter to fibre and soluble sugar equivalents. Research in such areas as fertilisation, cultural operations and irrigation needs to be pursued to optimise the partitioning of the biomass depending on market economies which will include consideration of price for products, processing costs and conversion efficiency. Work done in Japan has in this context indicated that high biomass cultivars may require more nitrogen and potassium than conventional sugarcane varieties.

Progress in research and development of sugarcane initiatives focussed only on the economic and environmental pillars of sustainability would not suffice to achieve the objective of higher productivity. Indeed it emerged at the workshop that less tangible factors such as trust, communication and coordination between growers and contractors or other stakeholders are equally important and should not be ignored. These factors have a direct impact on agronomic practices at field level as demonstrated in a study in South Africa where, in spite of climate, soils and terrain being well suited to sugarcane production, the reality over the past 10 years or more had been a persistent decline in yields and land abandonment. The study confirmed the occurrence of numerous improper practices at field level such as lengthy harvest to crush delays, poorly controlled burning, improper weed and fertiliser management, the root causes of which could all be traced back to social and organisational constraints at the local community levels rather than to lack of knowledge.

**Conclusions**

The workshop has been a success due to a large extent to the effort made by the local organising team led by Professor Gaspar Korndorfer. Research-wise, the workshop provided the opportunity to gauge the progress accomplished in sugarcane agronomy during the three years since the preceding workshop was held in Thailand in 2006. If there is no doubt that profitable and sustainable sugarcane production lies most importantly in soil organic matter conservation, particularly through green-cane harvesting, it is also clear that more effective techniques for incorporating the residues into the soil than current available methods remain a research challenge in many sugarcane growing areas of the world. The incidence of some negative results on productivity arising from trash blanketing has also served to emphasise that one solution could not fit all situations and each research finding requires testing under the specific local conditions prevailing in each country or state.
The workshop has also reinforced the awareness that the sugar industry in the world has common goals in agronomy, namely the search for alternatives to mineral fertilisers through research on green manuring and on biofertilisers, more efficient means of pest control, a more effective irrigation system and weed management so as to minimise production costs. However, the research and development in agronomy will not attain the desired goal of higher productivity if impeding factors such as trust and coordination among the stakeholders are not simultaneously addressed.

PRODUCTION SUCRIÈRE: INTÉGRATION ENTRE SUCRE, ALCOOL, RECYCLAGE DES RÉSIDUS ET DURABILITÉ – UN RAPPORT SUR L’ATELIER 2009 D’AGRONOMIE

Par

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MOTS-CLÉS: Productivité, Gestion de la Paille, Légumineuses, Irrigation, Fertilisation, Contrôle des Mauvaises Herbes.

Résumé

L’ATELIER DE travail 2009 en agronomie a eu lieu du 24 au 28 mai 2009 à Uberlândia, Brésil. Il a réuni quelque 70 participants dont 22 venaient de 13 pays différents d’outre-mer. L’atelier de travail a été un succès avec 33 présentations orales (et 16 posters), répartis sous cinq thèmes spécifiques: les nouvelles technologies pour la production durable de canne à sucre, la baisse de rendement en repousses et sa gestion, la modélisation de la croissance de la canne à sucre et de la production, la gestion des résidus du sol et de la plante, et le défi de la pression environnementale et de la stratégie pour le producteur de canne à sucre. L’atelier de travail a procuré l’occasion d’avoir un aperçu de l’industrie sucrière brésilienne, en particulier les pratiques culturales adoptées et l’état de la recherche et du développement dans ce pays. L’atelier de travail a également été l’occasion de rappeler aux technologues que l’optimisation de la production cannière requiert avant tout des semences de bonne qualité pour l’établissement des plantations et l’adoption d’une approche intégrée dans la gestion de la culture. Cette approche intégrée repose sur l’adoption de la technologie la plus adaptée en irrigation, fertilisation, contrôle des mauvaises herbes et protection de la culture. Bien qu’il soit admis que la viabilité du système de production de canne à sucre se trouve dans la conservation de la matière organique du sol, en particulier avec la récolte de la canne en vert, la gestion des résidus afin d’éviter la perte de productivité doit encore être étudiée. Il n’y aura pas d’application universelle du système de gestion des résidus, chaque système devant être testé selon les conditions locales spécifiques. L’atelier de travail a conscientisé les participants sur le fait qu’avec l’augmentation de la demande pour des variétés à forte teneur en fibre pour la cogénération, et la production de l’éthanol, le paradigme dans la recherche et le développement de la canne à sucre est appelé à se déplacer vers l’optimisation de la partition de la biomasse en faveur de la fibre. L’atelier de travail a également créé une prise de conscience que la recherche et les initiatives de développement n’atteindront pas les objectifs fixés de l’amélioration de la productivité si les contraintes sociales et organisationnelles ayant un impact négatif sur les pratiques agronomiques au niveau des champs ne sont pas résolues.
PRODUCCIÓN DE AZÚCAR: INTEGRACIÓN ENTRE AZÚCAR, ALCOHOL, UTILIZACIÓN DE RESIDUOS Y LA SUSTENTABILIDAD – INFORME SOBRE EL TALLER DE AGRONOMÍA 2009

Por

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PALABRAS CLAVE: Productividad, Manejo de Trash, Abono Verde, Irrigación, Fertilización, Control de Malezas.

Resumen
El TALLER de Agronomía 2009 se llevó a cabo del 24 al 28 de mayo de 2009 en Uberlandia, Brasil. Asistieron a él 70 participantes, de los cuales 22 habían cruzado el océano, arribando desde 13 países diferentes. El taller fue un éxito, con 33 presentaciones orales (y 16 pósteres) que versaron en los siguientes cinco temas específicos: nuevas tecnologías para una producción sustentable de azúcar, la disminución del rendimiento de la caña soca y su manejo, el uso de modelos para el crecimiento de la caña y su producción, el manejo del suelo y residuos de la planta y el desafío de la presión ambientalista y estrategias para el productor cañero. El taller también constituyó una oportunidad para reflexionar acerca de la industria azucarera en Brasil, en particular en lo que concierne a las prácticas culturales adoptadas allí y el estatus de la investigación que se lleva a cabo en el país y su desarrollo. El taller ha servido para recordarles a los tecnólogos que, para optimizar la producción de caña de azúcar, se requiere la utilización de semilla de alta calidad para establecer la plantación y la adopción de un enfoque integral del manejo del cultivo. Este enfoque integral para optimizar y aumentar la productividad involucra la adopción de las tecnologías más adecuadas para la irrigación, fertilización, control de malezas y protección del cultivo. Aunque se acepta la idea de que un sistema de producción de caña de azúcar sustentable se basa en la conservación de la materia orgánica del suelo, particularmente mediante la cosecha de caña en verde, se necesita aún investigar sobre manejo de residuos para evitar pérdidas en la productividad. No existe ni existirá un sistema de manejo de residuos universalmente aplicable, y cada sistema necesitará ser evaluado en las condiciones locales predominantes. Con la demanda creciente de cultivares con mayor contenido en fibra para la cogeneración y síntesis de bioetanol, la investigación y desarrollo de la agronomía de la caña de azúcar estará cada vez más focalizada en optimizar la partición de la biomasa a favor de la obtención de fibra. El taller también ha logrado que se tome conciencia de que si no se trabaja sobre las limitaciones sociales y organizativas que impactan negativamente en las prácticas agronómicas a nivel del campo, las iniciativas en investigación y desarrollo para aumentar la productividad no lograrán su cometido.
SUCCESSFUL SITE-SPECIFIC FERTILISATION WITH ORGANIC BY-PRODUCTS

By

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KEYWORDS: Organic Fertilisation, Site-Specific Management, Sugarcane, Waste Management.

Abstract
RAPIDLY increasing fertiliser prices are having a strong impact on the economics of sugarcane production. To control production costs, fertiliser applications are reduced and thus productivity is compromised. At the same time, pressure for proper management of organic, agro-industrial by-products is increasing as environmental regulations are becoming stricter. This situation provides for a unique, win-win opportunity to substitute expensive, synthetic fertilisers with readily available, organic by-products. At San Carlos Mill in Ecuador, we are using all the filter cake and vinasse from our own operation, and purchasing chicken manure from a large-scale chicken firm, in a site-specific fertilising schedule. The 17 845 ha plantation is divided into 1382 lots, and nutrient requirements are calculated for each lot individually based on soil and leaf analyses, cane variety, expected production, climate, and soil type. In 2008, we applied 49 249 t of filter cake and 13 023 t of chicken manure on 1506 and 2050 ha, respectively, of mainly plant cane. The organic by-products were applied fresh and supplemented with synthetic fertiliser where needed. Cane-tissue analyses and harvest data show that cane fertilised with organic by-products had similar growth and nutrient-uptake patterns, and recorded similar cane and sugar yields, compared to the cane that received only synthetic fertiliser, while fertilisation cost was reduced by up to 25%. In 2009, we have added the vinasse from the distillery to our fertilisation program and envisage purchasing only urea in the near future since, with the use of by-products, we are self-sufficient in P and K.

Introduction
Sugarcane removes large amounts of nutrients from the soil. Subirós Ruiz (2000) reports a wide range of values for nutrient uptake found in the literature, with an average value of 1.09 kg N, 0.24 kg P₂O₅ and 1.90 kg K₂O per tonne of cane (tc). Differences can be attributed to cane variety and nutrient availability in the soil.

As sugarcane is harvested, all the nutrients in the stalk are removed from the field; when cane is burned, additional nutrients are lost to the atmosphere (Núñez and Spaans, 2007). In order to avoid loss of soil fertility and maintain productivity of the land, these nutrients need to be returned to the soil. Since the green revolution, synthetic fertilisers have been the primary nutrient source, because; i) they are highly concentrated reducing storage, transportation, and application costs; ii) their nutrient content is well-known and uniform; and iii) once dissolved in the soil solution, they are readily available for plant uptake. Moreover, they were less expensive on a per kg nutrient basis compared to organic fertilisers.

Since 2004, however, synthetic-fertiliser prices have tripled and it appears that they will not be reduced in the near future (Figure 1). These high fertiliser prices have an enormous economic impact on sugarcane producers, as fertilisation is one of the principal components of the crop-management budget.
At the San Carlos Mill in Ecuador (2°13’14.61” S and 79°24’32.23” W), interest has always existed in the use of organic by-products from the factory as nutrient sources for the cane crop. However, manipulation and transport of the by-products used to be much more expensive compared to the use of conventional, synthetic fertilisers, as large quantities of organic products are needed because their nutrient content is relatively low.

Organic by-products that could serve as nutrient sources include filter cake (high P and medium N content), boiler ash (high P and K content), and vinasse (high K content). At the San Carlos Mill, filter cake and vinasse have been mixed with the irrigation water for the sugarcane crop since 1985, and the area that received this irrigation water (Sector 3, 3064 ha), has increased production ever since.

Prior to 1985, Sector 3 produced on the average 1 tc/ha less than the rest of the plantation (14,781 ha). After 1985, its productivity started to increase gradually and, since 1990, it has recorded 8 tc/ha more than the rest of the plantation, corresponding with a 12% productivity increase. Moreover, Sector 3 receives only N-fertiliser as soil analyses indicate high values of P and K, resulting in a lower production cost than other sectors that receive N, P and K fertilisers.

In accordance, Morris et al. (2007) reported that applying 246 t/ha of mill mud on a sandy soil one time before planting increased fresh cane and sucrose yields by 200% compared with low fertilisation treatments and 26% compared with adequate fertiliser treatments (two year average). Soil P and K also increased with this application of mill mud.

However, over that same period, sucrose recovery from Sector 3 has dropped from 0.4 kg sucrose/tc above, to 4.7 kg sucrose/tc below the average of the rest of the plantation. We attribute this to K build up in the soil from the vinasse to levels above 0.4 cmol/kg which result in reduced crystallisation of sucrose in the factory (Körndorfer, 1990). Another interesting observation is that, although P and K levels in the soil are much higher, the organic matter content in the soil is the same in Sector 3 compared to the rest. We suspect that the organic matter from the filter cake, that remains on the soil surface as the irrigation water infiltrates, is being burned at harvest. That would also explain why, in spite of receiving the same N application, foliar levels of N in the sugarcane of...
Sector 3 are similar to those of the rest of the plantation, since the N of the organic matter of the filter cake is also lost during the burning of the cane.

These results from an unreplicated field experiment provided practical evidence that filter cake and vinasse do break down in the soil and liberate nutrients to the soil. In field experiments in South Africa, Roth (1971) reported that the filter cake treatments, on average, gave highly significant increases in biomass yield when compared with the control but they also depressed sucrose content in cane. The results showed that bacteria, actinomycetes, fungi, and nematodes are closely associated with the increasing stability of the soil aggregates. The fungi in the control samples were only present in the form of spores or chlamydospores, and there was no pronounced mycelial network. By using different methods, it was possible to show that filter cake-treated soil had a very active mycelial network which was able to hold separate soil particles together.

The soils of Sector 3 have become quite rich in P and K and could sustain a healthy crop for many years even without receiving any more filter cake, vinasse or synthetic P and K fertilisers; in fact, the elevated K levels in the soil could be affecting sucrose recovery. In order to use these precious by-products in the rest of the plantation, however, they would have to be brought up-slope since irrigation is gravity fed, hence requiring a completely different application method.

As a response to the high fertiliser prices, in 2008 all the filter cake produced in the factory of San Carlos Mill and chicken manure purchased from a third party, were applied to mainly plant cane but also to ratoon cane, in P deficient soils. The objectives of this paper are to present the logistics of these commercial-scale operations, the model that was developed to incorporate the nutrients contained in the by-products into the fertilisation program, and the crop response and cost-benefit analysis of this operation.

**Site-specific, organic fertilisation**

The chicken manure was purchased from Ecuador’s largest chicken producer and the filter cake came from our own factory. Chemical analyses of the organic by-products used in the San Carlos Mill are presented in Table 1.

<table>
<thead>
<tr>
<th>Value</th>
<th>N (kg)</th>
<th>P₂O₅ (kg)</th>
<th>K₂O (kg)</th>
<th>Water (%)</th>
<th>Theoretical</th>
<th>Practical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filter cake</td>
<td>2.7±0.4</td>
<td>13±3</td>
<td>1.4±0.3</td>
<td>690±27</td>
<td>16.46</td>
<td>12.35</td>
</tr>
<tr>
<td>Chicken manure</td>
<td>15±2</td>
<td>22±4</td>
<td>19±4</td>
<td>240±46</td>
<td>64.14</td>
<td>48.11</td>
</tr>
<tr>
<td>Vinasse</td>
<td>–</td>
<td>7–10</td>
<td>–</td>
<td>–</td>
<td>12.75</td>
<td>9.56</td>
</tr>
</tbody>
</table>

The chemical composition of the by-products was periodically monitored to control their quality. The results from the filter cake are rather constant (Table 1). The chicken manure was also constant and any variation in nutrient content was most likely due to the cleaning cycles of the floor of the chicken barn.

Those from the vinasse fluctuated between 7 and 10 probably depending on the molasses–cane juice mix that is used in the distillery. Note that vinasse data are shown for reference purpose, since vinasse was not incorporated into the site-specific fertilisation program until 2009, and field evaluations are not available yet.
The efficiency of organic by-products depends on the availability of its nutrients, which in general is much higher for animal by-products than for vegetative material, because animal by-products can be considered an end-product of an optimum decomposition of vegetative material. Once applied to the soil, the decomposition rate depends on the microbial activity, which accelerates under conditions of medium-high temperatures, humidity and biodiversity.

Composting is usually recommended before applying organic by-products, mainly to control the decomposition process and obtain a higher quality product, but also to kill pathogens by the high temperatures generated during the composting process, and to reduce weight and water content and therefore transportation costs. Composting, however, is expensive both in investment of machinery and infrastructure, as well as in operation. We prefer to have the decomposition occur in the soil, stimulating biological activity where it is most needed and where liberated nutrients and leachates are immediately available for plant-uptake. Both filter cake and vinasse are exposed to high temperatures in the factory, so they should not contain pathogens. Chicken manure could contain animal-based pathogens, which we did not expect to affect the cane crop. In conclusion, we chose to apply the by-products directly to the soil without any prior treatment.

In our model to calculate fertiliser rates, we assumed conservative values for nutrient availability of the by-products, because we did not want to compromise cane production. Moreover, the sudden jump in synthetic fertiliser prices forced us to skip the experimental stage and to go straight to a commercial-scale application, and fortunately economic returns of the project were favourable enough that we could be conservative. Since filter cake is a raw vegetative material, the rate of release of both N and P was estimated at 50% in the first year and 25% in the second year. The remaining 25% would stay in the stable, humic fraction in the soil. The chicken manure was assumed to liberate 75% of its N and P in the first year, with 25% remaining in the humic fraction of the soil. Potassium does not form an integral part of the carbon structures because it does not form covalent bonds; instead, it only forms ionic bonds which do not require microbial breakdown, but only water for it to become available as K⁺ for plant uptake. We assumed an availability of 75% of the K in all by-products in the first year; the other 25% would be leached or maintained in the soil.

Taking into account these efficiencies, the practical, equivalent NPK-value can be calculated (Table 1). With respect to the practical value of filter cake, note that $8.75 is available in the first year and $3.60 the following year.

The plantations of the San Carlos Mill are divided into 1382 lots with an average size of 12.91 ha (Spaans and Núñez, 2006). On every lot, soil analysis is done immediately after harvest, and leaf analysis is done at 3.5, 5.5, 8.5 and 10.5 months after harvest. Soils are neutral, neither saline nor sodic, and rich in Ca and Mg. Therefore only urea, DAP and KCl are used in the fertilisation program. Based on soil and leaf analyses, cane variety, expected production, soil type and climate, the amount of N, P₂O₅ and K₂O that needs to be applied in every lot is being calculated.

On commercial lots, applications were made of either filter cake at a rate of 30 t/ha or chicken manure at a rate between 8–10 t/ha. The amount of by-product applied to a lot, multiplied by its nutrient content (see Table 1) and multiplied by the release rate discussed above, was subtracted from the total nutrient requirement of that lot. The difference was then applied separately by conventional means with synthetic fertilisers.

As a consequence of the site-specific management and the large number of lots, many different combinations of NPK application rates are used. Table 3 shows the most common nutrient requirements on San Carlos lots, and possible scenarios of how these nutrients were applied with by-products, synthetic fertiliser, or a combination of the two.

To evaluate the effect of the filter cake applications, in 2008 six pairs of commercial lots with plant cane were selected, such that within each pair both lots had the same soil type, planting
date, and cane variety; however, one lot was fertilised with synthetic fertiliser only and the other with a by-product and supplemented with synthetic fertiliser where needed. To evaluate the chicken manure application, seven pairs were selected in the same way. On every one of the selected lots, crop growth was monitored monthly by measuring stalk height and diameter on the same 10 plants in five sites within the lot; population was measured on the same five sites, counting the number of stalks present in 15 m. In addition, Crop-log data (Clements, 1970) in every lot were collected on plant tissue at 3.5, 5.5 and 8.5 months after crop-start date. During the harvest of 2009, cane yield and sucrose yield data of each lot were obtained from the commercial data.

Field operations

In order to process filter cake directly and without water, the filters were relocated outside the factory and the filter cake now falls directly into a dump truck. The filter-cake truck was then weighed on the same scales used to weigh the cane trucks, allowing for precise monitoring of filter cake production in the factory, an additional advantage of the project. The truck then proceeded to the field and dumped the filter cake on one side of the lot, where it accumulated until the total amount was deposited. Chicken manure was provided directly from the chicken barns to the mill by truck.

In the field, one front-loader lifted up the by-product from the ground and put it into a spreader. The spreader is a V-shaped wagon with a conveyor belt on the bottom that is driven by a hydraulic pump. The wagon has a volume of approximately 7 m$^3$ and can store 4 t of chicken manure or 6 t of filter cake. The team consisting of one front-loader, three 110 HP tractors each hauling a spreader and one supervisor could cover about 2.1 ha/h.

In plant cane, the equipment that makes the furrow also applied the synthetic fertiliser (where needed) in one single operation. Then either the chicken manure or the filter cake was applied in the furrow, the cane was planted on top of and in direct contact with the by-product, and then the furrow was closed and irrigation water applied. In ratoon cane, by-products were applied right after harvest in a separate operation. Then, the conventional equipment was used that in one single operation incorporates synthetic fertiliser, cultivates the inter-row, and reforms the furrow. Although the cultivation incorporates the by-products, these will never be placed as close to the roots of the cane stool as in plant cane. Therefore, in the selection of where to apply by-products, preference was given to plant cane.

Results and discussion

In 2008, 49 249 t of filter cake was applied to 1506 ha and 13 023 t of chicken manure to another 2050 ha, substituting 187 t of urea, 616 t of DAP and 314 t of KCl. Organic by-products contain all three macro nutrients in a more or less fixed proportion, and it is rare that their proportion matches exactly the sugarcane nutrient requirements of a lot. Thus, the amount of by-product to be applied in any lot can be calculated according to two strategies. One is fulfilling the requirement of all three nutrients, which inherently implies that two of the three nutrients will be applied in excess.

The other strategy is to apply only the amount necessary to fulfil the requirement of one nutrient, and complement the requirement of the other two with synthetic fertiliser. The second choice takes full advantage of the value of the organic by-product according to Table 1; however, a second application with synthetic fertiliser is needed. With the first choice, fertilisation is done in one operation, but the economic values reported in Table 1 will not be reached. Obviously, the optimum strategy will depend on the cost of acquisition, transport, and application of synthetic fertiliser and by-products.

Field evaluations

The evolution of stalk height and diameter throughout the growing season followed a normal pattern in all of the six pairs of lots for the filter cake evaluation (Figures 2 and 3), as well as in the seven pairs of lots for the chicken manure evaluation.
Fig. 2—Stalk height to the top visible dewlap of sugarcane fertilised with filter cake (♦) or synthetic fertiliser only (■). Each datum is an average of 300 plants. The data from the cane fertilised with chicken manure and its synthetic comparison (not shown) followed a similar pattern.

Fig. 3—Stalk diameter at the base of sugarcane fertilised with filter cake (♦) and synthetic fertilisers only (■). Each datum is an average of 300 plants. Data from the cane fertilised with chicken manure and its synthetic comparison (not shown) followed a similar pattern.

Detailed agronomic data for all evaluations from the pairs of lots are shown in Table 2. No significant differences in any of the agronomic parameters were found between the organically fertilised and the synthetically fertilised cane (Tukey test; P ≤ 0.05).
The Crop-log values (Table 2) for leaf-N and sheath-K levels at 3.5, 5.5 and 8.5 months after planting and P content of the stalk at 5.5 months, indicate that nutrient absorption occurred at normal rates for both organic fertilisations as compared to synthetic fertilisations. Since roughly the same amounts of nutrients were applied within each pair (organic-synthetic) of comparative lots, the data suggest that the liberation of nutrients from the organic by-products occurred at a sufficiently high rate to keep up with the instantaneous nutrient requirement of the crop, at any time. This is remarkable as no composting or any other pretreatment of the by-products was done.

One of the concerns of using organic fertiliser is the slow release of N and thus continuous N availability in the soil, possibly hampering the maturing of the crop. The data presented in Table 2, however, show that the decline of N content of the leaves as the cane develops follows a similar pattern in the organically compared to the synthetically fertilised cane.

We should bear in mind that the prime objective was not to improve crop production, but to substitute expensive synthetic fertiliser with readily available organic by-products to reduce costs. The results so far indicate that the assumptions in our model to quantify this substitution are valid.

In addition to the plant cane evaluations, we did similar observations on four pairs of ratoon cane lots. No significant differences (Tukey test; P ≤ 0.05) were found in any of the agronomic parameters between the ratoon cane fertilised with chicken manure compared to the cane fertilised with synthetic fertiliser.

| Table 2 | Growth indicators, Crop-log and yield data (average ± std) of sugarcane fertilised with filter cake and chicken manure, each compared with its synthetic fertiliser control fields. For growth indicators, n = 300 plants for filter cake evaluation, and n = 350 plants for chicken manure evaluation. Crop-log data are from five random plants selected in each lot, and cane and sucrose yield data were obtained from the commercial harvest of the entire lots. None of the agronomic parameters were significantly different (Tukey test; P ≤ 0.05), neither for the filter cake vs. its synthetic comparison, nor for the chicken manure vs. its synthetic comparison. |
In 2009, vinasse application was added as a component of the fertilisation program. To reduce transportation cost, 13 km of PVC pipes were installed in the ground to transport vinasse at a rate of 20 L/s to strategic sites in the field, where small ponds lined with double-plastic layers serve as buffers that can store up to 1 day of vinasse.

From these ponds, vinasse was mixed with the irrigation water at a rate of approximately 1:100. In lots that might drain into natural creeks, vinasse was not used for irrigation; instead vinasse was applied directly with a 12 m³ tanker hauled by a 140 HP tractor. Considering previous experiences in Sector 3 and the immediate availability of the K⁺ ion as discussed above, we expect that the vinasse will substitute KCl and that K uptake by the crop will be normal. So far, the logistics prove to be satisfactorily; field evaluation data, however, are not available yet.

**Cost/benefit analysis**

The cost/benefit analyses of possible nutrient requirements are presented in Table 3. The greatest savings using organic nutrient sources occurred when P and K requirements were high, because DAP and KCl were, in 2009, more expensive than urea. Fertilisation costs could be reduced by up to 25% with organic by-products, with the additional advantages of; i) incorporating organic material into the soil; ii) properly managing organic by-product, and iii) adding, in general, more P and K than necessary due to the difficulty of exactly matching the N-P-K proportion with organic by-products and fine tuning the amounts applied. Although not considered in Table 3, filter cake application is expected to save an additional $108/ha in the following year when the remaining nutrients will be released.

The use of organic by-products becomes less profitable when P and K requirements are lower, as the cost/benefit compared to synthetic fertilisers is reduced.

Costs and benefit will vary from one mill to another, depending on transportation cost and distance, chicken manure prices and efficiency in field logistics. Application costs ranged from US$27 (chicken manure) to US$33/ha (filter cake).

Transportation cost of the chicken manure was included in the price (US$28/t) as it was transported from the chicken barn directly to the lot, while transport of the filter cake from the mill to the lot averaged US$1.80/t. Investment in the spreaders (3), tractors (3) and front-loader (1) are in the order of US$220,000, which was paid back within the first year of the project. Application and transportation costs in Ecuador are relatively low due to highly subsidised fuel prices ($0.28/L diesel).

**Table 3**—Fertiliser rates and cost/benefit analysis for some of the most typical nutrient requirements calculated for San Carlos cane plantations. For every nutrient requirement, three possible scenarios are presented; using synthetic fertilisation (first row), chicken manure (second row) or filter cake (third row). As can be seen, chicken manure and filter cake fertilisations may require additional synthetic fertiliser depending on the rate applied and the specific nutrient requirement of the lot.

<table>
<thead>
<tr>
<th>Nutrients requirement</th>
<th>Chicken manure</th>
<th>Filter cake</th>
<th>Urea</th>
<th>DAP</th>
<th>KCl</th>
<th>Total cost</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>N–P2O5–K2O (kg/ha)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>120–130–130</td>
<td>–</td>
<td>150 283 217</td>
<td>–</td>
<td>150</td>
<td></td>
<td>$440</td>
<td>%</td>
</tr>
<tr>
<td>120–65–80</td>
<td>11</td>
<td>– 206 141 133</td>
<td>–</td>
<td>173</td>
<td>164</td>
<td>$321 27%</td>
<td></td>
</tr>
<tr>
<td>120–0–80</td>
<td>6</td>
<td>139 141</td>
<td>–</td>
<td>173</td>
<td>81</td>
<td>$249 19%</td>
<td></td>
</tr>
<tr>
<td>120–65–0</td>
<td>–</td>
<td>206 141</td>
<td>–</td>
<td>173</td>
<td>81</td>
<td>$188 1%</td>
<td></td>
</tr>
</tbody>
</table>
Conclusions

Organic by-products were successfully incorporated into the fertilisation program at San Carlos Mill in Ecuador. Organic nutrient application was fully mechanised and optimised so that by-products could substitute synthetic fertiliser in a wide range of nutrients requirements.

Due to high fertiliser prices, the cost-benefit of this project was extremely positive, but even at much lower fertiliser prices, the use of by-products is still profitable. Moreover, their contribution to the production system is not limited to providing N, P and K, but also in micro nutrients and valuable organic matter that improves soil structure and stimulates biological activity in the soil.

A field of one hectare that produces 80 t of cane produces about 2.4 t of filter cake which corresponds to 30 kg of P₂O₅, which, in turn, is similar to the amount of P extracted from the soil by that same crop. Thus, returning filter cake back to the soil completes the nutrient cycle for P and can as such be considered a sustainable practice.

The same is true for vinasse, which is the sink for all the K that was present in the cane juice. From a theoretical point of view this is logical, as the export products from the industry (sugar and ethanol) contain only C, H and O; all nutrients are removed in the process and evacuated as by-products. Requisite for the sustainability argument, however, is that the by-products are being returned to all fields that are being harvested, even the distant ones where transport costs are higher, including the fields of cane farmers that sell their cane to the mill.

We envisage that the only synthetic fertiliser that we will need in the future will be urea; DAP and KCl will be substituted entirely with filter cake and vinasse; if not, there are still other products such as chicken manure and boiler ashes to complement the fertilisation program.

REFERENCES


FERTILISATION ADAPTEE AU SITE AVEC DES SOUS PRODUITS ORGANIQUES

Par

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MOTS CLES: Fertilisation Organique, Gestion Adaptée au Site, Canne à Sucre, Gestion Des Déchets

Résumé

L’AUGMENTATION rapide des prix des engrais à un fort impact sur l’économie de la production de canne à sucre. Pour contrôler les coûts de production, les applications d’engrais sont réduites et la production est ainsi compromise. En même temps, l’incitation à bien gérer les sous produits agro-industriels organiques augmente du fait des lois environnementales qui deviennent de plus en plus strictes. Cette situation est une occasion unique de remplaces les engrais minéraux coûteux par des sous produits organiques facilement disponibles. À L’usine de San carlos, en Equateur, toutes les écumes et les vinasses produites, ainsi que les fientes de poules achetées à une société d’élevage sont utilisées dans un schéma de fertilisation adapté aux parcelles. Les 17845 ha de la plantation sont divisés en 1382 lots. Les besoins en éléments minéraux sont calculés pour chaque lot à partir des analyses de sol et des analyses foliaires: de la variété; de la production espérée; du climat et du type de sol. En 2008, nous avons épandu 49349 T d’écumes et 13023 T de fientes de poulet sur 1506 et 2050 ha respectivement, en majorité sur des cannes plantées. Les sous produits organiques furent appliqués en frais et complémentés avec des engrais minéraux quand il y en avait besoin. Les analyses de plantes et les résultats de récolte montrent que les cannes fertilisées avec des sous produits organiques avaient des croissances, des dynamiques de mobilisation, des rendements en canne et en sucre similaires à ceux des cannes fertilisées uniquement avec des engrais minéraux., alors que les coûts de fertilisation étaient réduits de 25%. En 2009, de la vinasse provenant de la distillerie a été ajoutée au programme de fertilisation et des achats uniquement d’urée sont envisagés dans un futur proche puisque avec l’utilisation des sous produits, les plantations sont autos suffisantes en P et en K.
UNA FERTILIZACIÓN DE SITIO ESPECÍFICO EXITOSA
CON SUBPRODUCTOS ORGÁNICOS

Por

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PALABRAS CLAVES: Fertilización Orgánica,
Manejo de Sitio Específico, Caña de Azúcar, Manejo de Desechos.

Resumen

EL RÁPIDO AUMENTO de los precios de los fertilizantes está causando un fuerte impacto en la economía de la producción de caña de azúcar. Para controlar los costos de producción se reduce la aplicación de fertilizantes y en consecuencia se compromete la productividad. Al mismo tiempo está aumentando la presión para un manejo apropiado de los subproductos orgánicos agroindustriales a medida que las regulaciones ambientales se vuelven más estrictas. Esta situación ofrece una oportunidad única para sustituir los caros fertilizantes sintéticos por subproductos orgánicos fáciles de conseguir. En el ingenio San Carlos en Ecuador, se está utilizando toda la cachaza y la vinaza proveniente de la fábrica y comprando estiércol de pollo a una firma productora de pollos en gran escala, lo cual se utiliza en un esquema de fertilización de sitio específico. Las 17 845 ha plantadas están divididas en 1382 lotes, y los requerimientos de nutrientes son calculados individualmente para cada lote en base a análisis de suelo, análisis foliares, cultivares, producción esperada, clima y tipo de suelo. En 2008 se aplicaron 49249 t de cachaza y 13023 t de estiércol de pollo en 1506 y 2050 ha, respectivamente, principalmente en caña planta. Los subproductos orgánicos se aplicaron frescos y suplementados con fertilizantes sintéticos donde fue necesario. Los análisis de tejidos de la caña y los datos de cosecha mostraron que la caña fertilizada con los subproductos orgánicos presentó similares patrones de crecimiento y absorción de nutrientes, y registró similares rendimientos de caña y azúcar, que la caña que recibió solamente fertilizantes sintéticos, mientras que el costo de fertilización se redujo hasta un 25%. En 2009, se incluyó la vinaza proveniente de la destilería al programa de fertilización y se prevé para el futuro próximo la compra solamente de urea, ya que con el uso de estos subproductos se será autosuficiente en P y K.
SPRAY VOLUME FOR THE CONTROL OF WEEDS IN SUGAR CANE

By


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KEYWORDS: Herbicides, Pesticide Application Technology, Imazapic, Droplet.

Abstract

The objective of this work was to evaluate the efficacy of different volumes of water for the application of imazapic in sugarcane and its effect on soil coverage and operational capacity. The minimum possible volumes applied by the sprayer (70 to 80 L/ha), 100, 150, 200 L/ha were compared to the processing plant’s standard (250 or 300 L/ha) in commercial fields with areas varying between 8 and 10 ha, at three periods within the crop season. During the applications, the parameters for operational capacity analysis were analysed. Soil coverage was evaluated by means of water-sensitive sampling and quantification through image analysis. Weed control was evaluated, on a visual basis, up to 150 days following application. All the treatments were efficient in controlling weeds up to 150 days following the treatments. The surface ranged from 8.34 to 51.81% and the gain in operational performance from 4.18 to 29.80%. Thus, imazapic applied with spray volumes from 70 L/ha, with a soil coverage of 8.34%, efficiently controlled the weeds in sugarcane when applied either at the beginning, in the middle, or at the end of the crop season, providing gains up to 29.80% in the application operational performance.

Introduction

By definition, pesticide application technology is the use of scientific knowledge to provide the correct usage of the biologically active product in the target, as required, in an economic way with minimal contamination of other areas (Matuo, 1990). Although it involves knowledge in different areas, the application technology is often restricted to the adoption of a spray volume per hectare, or at most to a volume associated with a specified droplet size. When technicians or producers are asked why they are using so many litres per hectare, the answers are often ‘I do not know’ or ‘because this is the most used one’. The volumes that have been used are almost never based on preliminary coverage, deposition and control evaluations or tests. Despite the little importance that has been assigned to it, the volume of water for pesticide application is currently one of the main items involved in the operating cost of phytosanitary treatments.

Sugarcane is not exempted from this rule. Despite the large areas and quality of the sprayers that have been used, particularly by the processing plants or big producers, the most commonly used volumes for herbicide application are pre-established, regardless of all the involved factors, and range from 200 to 300 L/ha. The fact that the application volume (L/ha) does not directly influence the biological result, once the amount of water per unit of area has been determined to facilitate the distribution of the active substance over the target surface (soil, straw or plant), with the necessary coverage, is simply not considered in the set up process. The reduction of the spray volume used for herbicide application will increase the equipment operating capacity, and can thus be an essential tool in reducing the application costs, besides the environmental gain associated with a decrease in water consumption. Proving the latter has been the objective of PROVAR – Programa de Valorização da Água em Pulverizações Agrícolas, a partnership between the Engineering and Automation Center of the Agronomic Institute (CEA/IAC), BASF S.A. and the sugarcane processing plants of the State of São Paulo.
Material and methods

The trials were conducted in commercial fields of six partner processing plants in the State of São Paulo: Buriti, Colorado, Santa Elisa Vale, Pedra, São Martinho and Cruz Alta. In all trials, the spraying equipment was similar to that used for commercial application, and was calibrated to deliver the following volumes: as little as possible applied by the sprayer (70 to 80 L/ha), 100, 150, 200 L/ha and the processing plant’s standard (250 or 300 L/ha). The standard conditions, as well as the treatments used in each of the trials, are described in Table 1.

While establishing the treatments, the type of spraying nozzle and the class of the droplet size were kept unchanged and compared to the standard adopted by the processing plants. Only the flow and the working pressure of the nozzles were changed to adjust to the different volumes. The lowest pressure considered in the establishment of the minimum application volume was 1.5 bar as, with pressures close to 1.0 bar, failures are likely to occur in spraying once it is very close to the anti-dropping device opening pressure; the latter will prevent the system from working appropriately and, thus, negatively affecting the quality of the application. Furthermore, nozzles using 100 mesh sieves were not considered as they could increase the risk of retaining products in the filters, affecting the operational efficiency.

Table 1—Equipment, sprayers set up and treatments data.

<table>
<thead>
<tr>
<th>Application conditions</th>
<th>Processing plant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sta Elisa Vale</td>
</tr>
<tr>
<td>Tractor</td>
<td>MF 2585</td>
</tr>
<tr>
<td>Speed (km/h)</td>
<td>10</td>
</tr>
<tr>
<td>Sprayer</td>
<td>FMCopling</td>
</tr>
<tr>
<td>Tank capacity (L)</td>
<td>1400</td>
</tr>
<tr>
<td>Nozzles</td>
<td>TTI 11003</td>
</tr>
<tr>
<td>Nozzles on the boom</td>
<td>27</td>
</tr>
<tr>
<td>Spacing between the nozzles (m)</td>
<td>0.50</td>
</tr>
<tr>
<td>Spray volume (L/ha)</td>
<td>200</td>
</tr>
<tr>
<td>Drop size</td>
<td>XC</td>
</tr>
<tr>
<td>Treatments</td>
<td>250/300 L/ha</td>
</tr>
<tr>
<td>Nozzle</td>
<td>AVI 11005</td>
</tr>
<tr>
<td>Droplet size</td>
<td>VC</td>
</tr>
<tr>
<td>200 L/ha</td>
<td>TTI 11003</td>
</tr>
<tr>
<td>Nozzle</td>
<td>XC</td>
</tr>
<tr>
<td>150 L/ha</td>
<td>TTI 11003</td>
</tr>
<tr>
<td>Nozzle</td>
<td>XC</td>
</tr>
<tr>
<td>100 L/ha</td>
<td>TTI 11002</td>
</tr>
<tr>
<td>Nozzle</td>
<td>XC</td>
</tr>
<tr>
<td>Minimum</td>
<td>L/ha</td>
</tr>
<tr>
<td>Nozzle</td>
<td>TTI 11002</td>
</tr>
<tr>
<td>Droplet size</td>
<td>XC</td>
</tr>
</tbody>
</table>

(1) C = Coarse, VC = Very Coarse and XC = Extremely Coarse

The applications were conducted in the Beginning (June–July), Middle (August–September) and End (October–November) of the crop season and the environmental conditions were monitored, but not controlled, in an attempt to represent the real application conditions. During spraying, the temperature ranged between 20–35, 18–39 and 21–35°C, the relative humidity between 19–65, 15–80 and 15–87%, and the wind speed between 0.3–6, 0.1–7.1 and 0.4–4.4 m/s, respectively to
Beginning, Middle and End applications. Imazapic (Plateau) was standardised as the herbicide to be used in all the areas, so that it did not constitute a source of variation, with doses ranging between 140 g/ha and 240 g/ha, according to the soil texture and weeds population.

Each treatment, represented by a spraying volume, was established in a commercial stand with approximately 10 hectares of cane harvested either in green (application over straw) or after burning (application over the soil).

In trials carried out at the beginning of the crop season, for each treatment, an untreated area was maintained without application with a width corresponding to the extension of the spraying boom by 10 m length. In the other trials, 3 similar areas were maintained untreated, in order to evaluate the weeds that were present.

In order to allow a soil coverage analysis and subsequently relate it to the control, 6 water-sensitive paper leaves were placed under the spray boom in the treated area, 3 of them were placed under the right boom and 3 under the left sprayer boom.

After spraying, the papers were stored into paper bags duly identified and forwarded to the laboratory for coverage analysis. In the laboratory, the water-sensitive papers were digitised through a 'scanner' and the images obtained were analysed with the image analysis IDRISI software, in order to determine the coverage percentage from colour contrast, in compliance with the method developed and evaluated by Firveda et al. (2002).

To assess the efficacy of the different treatments on weed control, untreated and selected sampling points were assigned total or specific coverage percentage scores for the species at 30, 60, 90, 120 days after the application; and, where possible depending on the culture size, also at 150 days after the application.

The scores were individually assigned by each of the 3 duly-trained observers. Five sampling points were randomly chosen, by walking between an untreated area and the other within the parcel, following the W pattern.

The observers attributed a general coverage percentage score between 0 to 100% for the weed population observed in the parcel, 0 corresponding to the absence of infestation and 100% to total area infestation (general coverage related to the observed area). Subsequently, five species were identified in the parcel and a visual grading of specific frequency was assigned to the individual weeds, the sum of the five grades reaching 100%. The data collected were used for the calculation of the percentage control. The control scores were submitted to variance analysis according to the design proposed and, when significant differences were observed, the averages were compared by Tukey test at 5% probability.

During the entire operation, in order to allow the economic comparison based on the adoption of the different volumes that have been considered, the times related to refilling the sprayer with the spray solution, carrier manoeuvres, emptying the spraying tank, the time required to move from refilling to the application areas were collected, in addition to the measurement of the stand’s length.

The gain in operational capacity, calculated based on the time required to spray one ha, was analysed considering the following formula proposed by Matuo (1990):

\[
t = \frac{10000 + 10000 \cdot TV + d \cdot v + Tr \cdot V}{Vp \cdot L \cdot C \cdot L \cdot Vd \cdot Ca \cdot Ca}
\]

where:

- \( t \) = Time required to spray 1 hectare (min/ha).
- \( Vp \) = Spraying speed (m/min).
- \( L \) = Width of the spraying area (m).
Tv = Turn time (min).
C  = Length of the treatment area (m).
D  = Total covered distance in each refilling (m).
V  = Spraying volume (L/ha).
Vd = Forward speed for refilling (m/min).
Ca = Tank capacity (L).
Tr = Time for tank refilling (min).

Results and discussion

A sample of the surface coverage obtained by each of the different treatments is shown in Figure 1.

According to data obtained (Table 2), soil coverage ranged from 8.34 to 51.81%, and the coverage of the control could be compared with the other treatments.

Table 2—Coverage means obtained from the water-sensitive papers in the different treatments, processing plants, and application timing.

<table>
<thead>
<tr>
<th>Processing plant</th>
<th>Treatments (L/ha)</th>
<th>Coverage</th>
<th>Droplet(1)</th>
<th>Min</th>
<th>100</th>
<th>150</th>
<th>200</th>
<th>250</th>
<th>300</th>
<th>Mean coverage (%) (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colorado Green</td>
<td>C</td>
<td>8.65</td>
<td>14.94</td>
<td>28.42</td>
<td>45.78</td>
<td>50.87</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colorado Burnt</td>
<td>C</td>
<td>8.84</td>
<td>15.09</td>
<td>24.26</td>
<td>40.12</td>
<td>48.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cruz Alta</td>
<td>Green XC</td>
<td>8.77</td>
<td>17.45</td>
<td>30.40</td>
<td>35.46</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>40.80</td>
</tr>
<tr>
<td>Sta Elisa Green</td>
<td>XC</td>
<td>8.34</td>
<td>16.63</td>
<td>28.29</td>
<td>44.36</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sta Elisa Burnt</td>
<td>XC</td>
<td>8.34</td>
<td>16.63</td>
<td>28.29</td>
<td>44.36</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>São Martinho</td>
<td>Green VC</td>
<td>13.09</td>
<td>32.63</td>
<td>34.15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>51.81</td>
</tr>
<tr>
<td>Pedra Burnt</td>
<td>VC</td>
<td></td>
<td></td>
<td>12.22</td>
<td>16.74</td>
<td>22.50</td>
<td>38.73</td>
<td>51.81</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buriti</td>
<td>Green VC</td>
<td>10.70</td>
<td>14.57</td>
<td>28.32</td>
<td>34.86</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(1) C = Coarse, VC = Very Coarse and XC = Extremely Coarse  
(2) Mean coverage of Beginning, Middle and End phases

The visual control evaluations have not shown significant differences for any of the considered volumes, application timing or processing plant. Thus, soil coverage up to 8.34%, such as those obtained in the coverage evaluation, was sufficient to reach the maximum efficacy of the herbicide.

It should be noted that imazapic is a high solubility herbicide and, therefore, has high redistribution capacity in soil solution and penetration in straw. It may be that such coverage would not be applicable to some very low solubility herbicides.

The mean operational data of the three application times are described in Table 3.
Table 3—Identification of the operational mean data of the three herbicide application timings in sugarcane.

<table>
<thead>
<tr>
<th>Analysed item</th>
<th>Processing plant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Buriti</td>
</tr>
<tr>
<td></td>
<td>Green</td>
</tr>
<tr>
<td>Filling (min)</td>
<td>15.53</td>
</tr>
<tr>
<td>Manoeuvre (min)</td>
<td>0.47</td>
</tr>
<tr>
<td>Dry the Tank (min)</td>
<td>64.5</td>
</tr>
<tr>
<td>Shot (min)</td>
<td>7.51</td>
</tr>
<tr>
<td>Moving to the area (min)</td>
<td>4.65</td>
</tr>
<tr>
<td>Stand length (m)</td>
<td>564.00</td>
</tr>
</tbody>
</table>

The operational capacities at the three timings of application, considering the mean data obtained from each processing plant, are presented in Table 4.

The operational capacities were not very different between the processing plants, except for Cruz Alta and Pedra where the ready-to-use spray-mixture system has already been adopted, with considerably reduced filling and filling moving times.

In all of them, the operational capacity gain was significant, ranging between 4.18 and 29.80%.

Table 4—Mean time required to spray 1 ha using different spray volumes.

<table>
<thead>
<tr>
<th>Volumes</th>
<th>Buriti</th>
<th>Colorado</th>
<th>Cruz Alta</th>
<th>Vale do Rosário</th>
<th>São Martinho</th>
<th>Pedra</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Green</td>
<td>Green</td>
<td>Burnt</td>
<td>Green</td>
<td>Burnt</td>
<td>Green</td>
</tr>
<tr>
<td>Minimum</td>
<td>6.25</td>
<td>6.84</td>
<td>6.71</td>
<td>6.05</td>
<td>6.28</td>
<td>2.46</td>
</tr>
<tr>
<td>100</td>
<td>6.54</td>
<td>7.04</td>
<td>6.94</td>
<td>2.75</td>
<td>6.40</td>
<td>6.68</td>
</tr>
<tr>
<td>150</td>
<td>7.26</td>
<td>7.38</td>
<td>7.33</td>
<td>3.04</td>
<td>6.97</td>
<td>7.35</td>
</tr>
<tr>
<td>200</td>
<td>7.98</td>
<td>7.72</td>
<td>7.71</td>
<td>3.33</td>
<td>7.54</td>
<td>8.02</td>
</tr>
<tr>
<td>250/300</td>
<td>8.06</td>
<td>8.10</td>
<td>3.92</td>
<td></td>
<td></td>
<td>3.25</td>
</tr>
</tbody>
</table>

Conclusions

The results showed that imazapic (Plateau) applied with spray volumes from 70 L/ha efficiently controlled weeds in sugarcane when applied at the beginning, middle or end of crops. As the level of control was not adversely affected, the adoption of lower water volumes may represent reduced application operating costs for the processing plants, ranging from 4.18 to 29.80% of the total invested amount.

REFERENCES


EFFET DES VOLUMES DE BOUILLIE SUR LA MAITRISE DES MAUVAISES HERBES EN CANNE À SUCRE

Par
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MOTS-CLÉS: Herbicides, Technique d’Application des Pesticides, Imazapic, Gouttelette.

Résumé
L’OBJECTIF de ce travail était d’évaluer l’efficacité de différents volumes de bouillie pour l’application d’imazapic en canne à sucre, ainsi que leur taux de couverture du sol et les aspects opérationnels. Les quantités minimum applicables par le pulvérisateur (70 à 80 l/ha, 100, 150 et 200 l/ha) ont été comparées aux volumes standards qui sont de 250 à 300 l/ha; les essais ont été conduits sur des parcelles de cultures commerciales de 8 et 10 ha à trois périodes de la saison culturelle. Au cours des applications, les paramètres de la pulvérisation ont été analysés. La couverture du sol a été évaluée grâce à des papiers hydrosensibles traités par analyse d’image. La maîtrise des mauvaises herbes a été estimée par des contrôles visuels jusqu’à 150 jours après l’application. Tous les traitements ont été efficaces sur l’enherbement jusqu’à 150 jours après l’application. Les surfaces couvertes variaient de 8.34 à 51.81% et les performances de l’opération étaient améliorées de 4.18 à 29.80%. Ainsi, l’imazapic appliqué avec une bouillie à 70 l/ha avec une couverture du sol de 8.34% a maîtrisé efficacement les mauvaises herbes en canne à sucre que l’application soit effectuée au début, au milieu ou à la fin de la saison de culture, en apportant un gain de performance atteignant 29.80%.

VOLÚMEN DE PULVERIZACION PARA EL CONTROL DE MALEZAS EN CAÑA DE AZÚCAR

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PALABRAS CLAVES: Herbicidas, Tecnología de Aplicación

Resúmen
EL OBJETIVO de este trabajo fue evaluar la eficacia de diferentes volúmenes de agua para la aplicación de imazapic en caña de azúcar, y su efecto en la cobertura del suelo y en la capacidad operativa. Se compararon volúmenes de aplicación, en tres diferentes periodos dentro de la estación de crecimiento, entre el mínimo posible aplicado por la pulverizadora (70 a 80 l/ha), 100, 150 y 200 L/ha, con los estándares utilizados en el cultivo (250 o 300 L/ha) en lotes comerciales con superficies de entre 8 y 10 ha. Durante las aplicaciones, se analizaron los parámetros para el análisis de capacidad operativa. Se evaluó la cobertura del suelo a través de muestreo hidro-sensible que fue evaluado utilizando análisis de imágenes. Se evaluó el control de malezas, en forma visual, hasta 150 días después de la aplicación. Todos los tratamientos fueron eficientes para el control de malezas hasta los 150 días. La cobertura tuvo un rango de 8.34 a 51.81% y la ganancia en desempeño operativo varió de 4.18 a 29.80%. De este modo, imazapic aplicado con volúmenes de aplicación de 70 L/ha, con una cobertura de suelo de 8.34%, controló eficientemente las malezas en caña de azúcar tanto en aplicaciones al inicio, mitad o final del periodo de crecimiento, generando ganancias de hasta 29.80% en la capacidad operativa de la aplicación.
USE OF ORGANOMINERAL FERTILISERS ON SUGARCANE PRODUCTIVITY IN A TYPIC HAPLUSTOX SOIL

By

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KEYWORDS: Alternative Fertiliser, Organomineral, Organic Matter, Sugarcane.

Abstract

The association of organic manure with mineral fertiliser, called organomineral fertiliser, combines the benefits of organic manure through the improvement of the physical, chemical and biological soil qualities with the efficiency of the mineral fertiliser provided by its high solubility and ready availability of nutrients in the soil solution. The objective of this study was to evaluate the efficiency of organomineral fertiliser in sugarcane productivity in a dystrophic soil. The statistical design was a randomised block with seven treatments and four replicates. The treatments consisted of a control (without fertilisation), three rates of a ternary chemical fertiliser providing 50, 100, 150 kg/ha each of K₂O and P₂O₅ and 10, 20, 30 kg N/ha, three rates of an organomineral fertiliser providing 50, 100, 150 kg/ha of K₂O and P₂O₅ and 7.5, 15, 22.5 kg N/ha. Lime was broadcast over the total area, 30 days before planting at the rate of 2.0 tonnes per hectare and the fertilisers were applied in the furrows at planting. The variety of cane used was SP81 3250. The results obtained from this study showed that fertilisation with organomineral fertiliser or conventional chemical fertiliser, in dosages that provided 100 and 150 kg/ha of K₂O and P₂O₅ produced the same yields of sugarcane. In relation to the technological traits, the two sources of fertiliser applied in the same dosages promoted the same values for Pol % cane and ATR (Total Recoverable Sugar). For fibre % cane, a difference was observed. The treatments with the doses of 50 and 100 kg/ha of K₂O and P₂O₅ in chemical form and 150 kg/ha of K₂O and P₂O₅ as organomineral form promoted the lowest levels of fibre % cane.

Introduction

The use of new technologies in sugarcane fertilisation has become necessary in the face of the expansion of the sugarcane growing areas on sandy soils with natural low soil fertility. In these soils, nutrient leaching and volatilisation, especially potassium and nitrogen, can be a problem due to the low CEC, and may decrease sugarcane yield. Under these conditions, the integrated use of organic and mineral forms of fertilisers, named organomineral fertilisers, may be more beneficial, as the organic fertilisation will lead to an improvement of the physical, chemical and biological qualities together with the proven efficiency of mineral fertilisation.

The addition of organic matter to soils is known to improve soil physical characteristics resulting in reduced soil bulk density, improved water holding capacity as a result of the aggregation of particles of sand, silt and clay by organic matter (Alves, 1997).

The organic material applied or existing in soil can also provoke modifications in its chemical properties such as nutrient furnishing, toxicity amendment, pH, CEC, and humus content (Kiehl, 1985).

The objective of this work was to evaluate the efficiency of organomineral fertilisation on sugar yield compared with mineral fertilisation on Typic Haplustox.
Materials and methods

The assay was conducted in the town of Altinópolis, SP- Brazil, on Typic Haplustox, the chemical analysis of which is in Table 1.

The cane variety used was SP813250, with the following characteristics: high agricultural yield, high sucrose content, good tillering, medium maturation and tolerant to the main diseases.

![Table 1—Soil characteristics at study site](image)

<table>
<thead>
<tr>
<th>Properties</th>
<th>Depth 0–20 cm</th>
<th>Depth 20–40 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH (CaCl₂)</td>
<td>4.6</td>
<td>4.5</td>
</tr>
<tr>
<td>M.O (mg/dm³)</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>P (mg/dm³)</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>K (mmol/dm³)</td>
<td>0.8</td>
<td>0.4</td>
</tr>
<tr>
<td>Ca (mmol/dm³)</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Mg (mmol/dm³)</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>H + Al (mmol/dm³)</td>
<td>20</td>
<td>19</td>
</tr>
<tr>
<td>S.B (mmol/dm³)</td>
<td>7.8</td>
<td>6.4</td>
</tr>
<tr>
<td>CEC (mmol/dm³)</td>
<td>27</td>
<td>25</td>
</tr>
<tr>
<td>V (%)</td>
<td>26.6</td>
<td>26.4</td>
</tr>
</tbody>
</table>

The experimental design was randomised blocks with 7 treatments and 4 replicates. The treatments are described in Table 2.

![Table 2—Description of the treatments.](image)

<table>
<thead>
<tr>
<th>Treatments</th>
<th>kg N/ha</th>
<th>kg K₂O/ha</th>
<th>kg P₂O₅/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1 – Control</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>T2 – Chemical fertiliser</td>
<td>10</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>T3 – Chemical fertiliser</td>
<td>20</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>T4 – Chemical fertiliser</td>
<td>30</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>T5 – Organomineral fertiliser</td>
<td>7.5</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>T6 – Organomineral fertiliser</td>
<td>15</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>T7 – Organomineral fertiliser</td>
<td>22.5</td>
<td>150</td>
<td>150</td>
</tr>
</tbody>
</table>

The organomineral fertiliser used has the formulation of 3% of N, 12% of P₂O₅ and 12% of K₂O with minimal warrant of 25% of dry matter, due to the Brazilian Legislation. The mineral fertiliser had 4% N, 20% P₂O₅ and 20% K₂O.

The experimental plots were made up of five rows of sugarcane, spaced 1.4 m apart, 10 m in length. The assay planting was performed in March of 2007 and the crop was harvested in August of 2008.

Cane yield was evaluated through weighing in the useful area of each plot, and the technological characteristics by removing ten stalks from each plot for determination of fibre % cane, Pol % cane and ATR kg/t.

The F test was used to evaluate the effect of the treatments on the investigated variables and Scott-Knott test at the level of 10% of probability for comparison between means.

Results and discussion

Cane yield

The average results for cane yield are presented in Table 3. The treatment which was not given any chemical or organomineral fertilisation had lower cane yield (TCH), indicating nutrient
shortage and the need for nutrient mineral complementation, characteristic of dystrophic soils in nutrient furnishing for crops. This agrees with Raij et al. (1996) who recommended a dose of 120 kg/ha of P₂O₅ and K₂O to soils with low content of K₂O and P₂O₅.

In the treatments which were given doses of 100 and 150 kg/ha of P₂O₅ and K₂O, either in the chemical or organomineral form, the yield means obtained were equal to one another and higher than the other treatments.

It can be observed that the nitrogen rates were low. However, they did not affect significantly the yield of cane. This can be explained by the edaphoclimatic conditions found in Brazil where the plant cane has shown low response to nitrogen fertilisation, mainly due to a better efficiency of biological fixation and other biotic factors that improve the use of nitrogen from the soil by plant.

When applying two sources of fertilisation, one strictly mineral and the other which possesses organic matter, promoting similar yield, it is advisable to choose the source which adds organic matter, since it promotes improvements in the physical, chemical and biological properties of soil. It will also contribute to future increases in agricultural yield.

<table>
<thead>
<tr>
<th>Sources</th>
<th>Kg/ha P₂O₅ K₂O</th>
<th>Cane yield t/ha</th>
<th>Fibre (%)</th>
<th>Pol (%) cane ATR (%) Cane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0 0 0</td>
<td>54.78 c</td>
<td>13.33 a</td>
<td>15.84 a 154.74 a</td>
</tr>
<tr>
<td>Chemical</td>
<td>10 50 50</td>
<td>74.07 b</td>
<td>12.15 c</td>
<td>16.36 a 159.46 a</td>
</tr>
<tr>
<td>Chemical</td>
<td>20 100 100</td>
<td>85.63 a</td>
<td>12.13 c</td>
<td>16.51 a 161.15 a</td>
</tr>
<tr>
<td>Chemical</td>
<td>30 150 150</td>
<td>85.42 a</td>
<td>12.55 b</td>
<td>16.58 a 161.71 a</td>
</tr>
<tr>
<td>Organomineral</td>
<td>7.5 50 50</td>
<td>75.37 b</td>
<td>12.64 b</td>
<td>16.45 a 159.95 a</td>
</tr>
<tr>
<td>Organomineral</td>
<td>15 100 100</td>
<td>92.54 a</td>
<td>12.50 b</td>
<td>16.28 a 158.96 a</td>
</tr>
<tr>
<td>Organomineral</td>
<td>22.5 150 150</td>
<td>93.82 a</td>
<td>11.86 c</td>
<td>16.41 a 160.10 a</td>
</tr>
</tbody>
</table>

Technological characteristics

The average values obtained for the technological characteristics are presented in Table 3. As far as the chief technological characteristics are concerned, one can observe that use of fertilisation in the organomineral and chemical form, both at the same dosages of nutrients, promoted values statistically equal for contents of Pol % cane and total recoverable sucrose % cane.

Nevertheless, for the contents of fibre % cane, a difference can be noticed among the treatments. To a treatment which was given no source of fertilisation, the fibre content was higher than the other treatments, brought about by the decreased yield, causing less accumulation of sugars and hence an increased proportion of fibre in the stalks.

For the treatments which received doses of 150 kg/ha of K₂O and P₂O₅ in the organomineral form and 100 and 50 kg/ha of K₂O and P₂O₅ in the mineral form, there was decreased fibre content, when compared with the other treatments.

As yield is increased, promoted by the efficiency of fertilisation, a greater accumulation of photoassimilates (sucrose) occurs, to the detriment of fibre content.

Conclusions

The organomineral fertiliser provided the same agricultural and technological yield in sugarcane as the mineral fertiliser in plant cane.
So, it is suggested that the study of organomineral fertiliser and its effects on long-term productivity be the subject of future studies.

REFERENCES


EFFET DES ENGRAIS ORGANOMINERAUX SUR LA PRODUCTIVITÉ DE LA CANNE À SUCRE DANS UN SOL HAPLUSTOX TYPIQUE

Par

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MOTS-CLÉS: Engrais Alternatif, Engrais Organomineral, Matière Organique, Canne à Sucre.

Résumé

L'association d'engrais organique avec de l'engrais minéral, appelée engrais organominéral, combine les avantages de l'engrais organique par l'amélioration des qualités physiques, chimiques et biologiques du sol avec l'efficacité de l'engrais minéral due à sa solubilité élevée et à la disponibilité rapide des éléments minéraux dans la solution de sol. L'objectif de cette étude était d'évaluer l'efficacité de l'engrais organominéral sur la productivité de la canne à sucre dans un sol dystrophique. Un dispositif statistique en blocs randomisés avec sept traitements et quatre répétitions a été utilisé. Les sept traitements étaient composés d'une témoin (sans fertilisation), trois doses d'engrais chimique ternaire fournissant respectivement 50, 100 et 150 kg/ha de K₂O et P₂O₅, et 10, 20, 30 kilogrammes de N/ha, et enfin de trois doses d'engrais organominéral fournissant respectivement 50, 100 et 150 kg/ha de K₂O et P₂O₅, et 7.5, 15 et 22.5 kilogrammes de N/ha. Ces engrais ont été appliqués dans le sillon à la plantation. De la chaux a été épandue en surface, 30 jours avant la plantation, à la dose de 2.0 tonnes par hectare. La variété de canne utilisée était la SP 81/3250. Les résultats ont montré, qu’aux doses de 100 et 150 kg/ha de K₂O et de P₂O₅, l'engrais organominéral et l'engrais chimique conventionnel produisaient les mêmes rendements de canne à sucre. En ce qui concerne la qualité technologique, les deux types d'engrais appliqués aux mêmes doses ont donné les mêmes valeurs de Pol % de canne et d’ATR (sucre récupérable total). Par contre, des différences ont été observées pour la fibre % canne. Les traitements avec des doses de 50 et 100 kg/ha de K₂O et P₂O₅ sous forme chimique et celui avec une dose de 150 kg/ha de K₂O et de P₂O₅ sous forme organominérale ont produit les teneurs en fibre % canne les plus basses.
USO DE FERTILIZANTES ORGANOEMINERALES EN LA PRODUCTIVIDAD DE LA CANA DE AZÚCAR EN UN SUELO TÍPICO HAPLUSTOX

Por

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PALABRAS CLAVE: Fertilizante Alternativo, Organomineral, Materia Orgánica, Cana de Azúcar.

Resumen
La asociación de abono orgánico con fertilizante mineral, comúnmente denominada fertilizante organomineral, combina los beneficios del abono orgánico en el mejoramiento de las propiedades físicas, químicas y biológicas del suelo, con la eficiencia del fertilizante mineral, la cual es producto de su alta solubilidad y disponibilidad inmediata de nutrientes en la solución del suelo. El objetivo del presente estudio era evaluar la eficiencia del fertilizante organomineral en la productividad de la caña de azúcar en un suelo distrofico. La evaluación se realizó con un diseño experimental bloques al azar con siete tratamientos y cuatro repeticiones. Los tratamientos consistieron de un testigo (sin fertilización), tres dosis de un fertilizante químico triple, para proveer 50, 100 y 150 kg/ha de ambos K₂O y P₂O₅ y 10, 20, 30 kg N/ha, tres dosis de un fertilizante organomineral para proveer 50, 100 y 150 kg/ha de ambos K₂O y P₂O₅ y 7.5, 15 y 22.5 kg N/ha. Se aplicó cal en todo el área 30 días antes de la siembra, en una dosis de 2 toneladas por hectárea y los fertilizantes se aplicaron en el surco al momento de la siembra. Se plantó la variedad SP81-3250. Los resultados del estudio demuestran que la aplicación de fertilizante organomineral o el convencional químico, en dosis que provean 100 y 150 kg/ha de K₂O y P₂O₅, produjo los mismos rendimientos para caña de azúcar. Respecto a los caracteres tecnológicos, las dos fuentes de fertilizante, aplicadas en la misma dosis, produjeron los mismos valores de Pol% cana y ATR (Total de azúcar recuperable). Se observó una diferencia en cuanto a porcentaje de fibra en cana. Los tratamientos con dosis de 50 y 100 kg/ha de K₂O y P₂O₅ en forma química y 150 kg/ha de K₂O y P₂O₅ en forma organomineral produjeron menor porcentaje de fibra en cana.
PERSISTENCE OF HERBICIDES APPLIED TO SUGARCANE DURING THE RAINY SEASON IN BRAZIL

By

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KEYWORDS: Weed Management, Pre-Emergence Control, Cane Trash.

Abstract

This research aimed to study the persistence of herbicides in soil after the rainy season, evaluated by weed control in sugarcane. A split-plot design was used with main-plots consisting of six sugarcane rows (37.5 m²) and sub-plots one cane row (7.5 m²). Seeds of Ipomoea quamoclit, Ipomoea hederifolia, Merremia cissoides, Panicum maximum and Brachiaria decumbens were sown in the sub-plots while the main-plots consisted of ten herbicide treatments as follows: an untreated control, imazapic (147 g/ha), imazapic (98 g/ha) + sulfentrazone (600 g/ha), sulfentrazone (800 g/ha), tebuthiuron (1000 g/ha), amicarbazone (1400 g/ha), flumioxazin (125 g/ha), diuron (1066 g/ha) + hexazinone (134 g/ha) + imazapic (98 g/ha), amicarbazone (840 g/ha) + isoxaflutole (82.5 g/ha), imazapic (98 g/ha) + isoxaflutole (85 g/ha). During the 120 days following spraying, 698.7 mm of rainfall was observed, the average minimum and maximum temperature being 21.9 and 30.6°C respectively. The herbicides that best resisted this weather had a satisfactory control on the species studied in the following descending order: amicarbazone (91.2% control), imazapic (90.8%), imazapic + sulfentrazone (89.6%), amicarbazone + isoxaflutole (89.2%), imazapic + isoxaflutole (85.6%), diuron + hexazinone + imazapic (84.4%), tebuthiuron (76%), sulfentrazone (70.8%), flumioxazin (19.2%).

Introduction

Concerning Ipomoea spp., the usual method of control is chemical, which, according to Siebert et al. (2004), is conducted in pre-emergence in early spring. During that period, the more intense rainfall associated with high temperatures may cause faster degradation of residual herbicides in soil (Viator et al., 2002). The persistence of some herbicides in the soil is extremely variable. Some herbicides may be degraded within days, while others may persist for several months or years; however, the time they remain active in the soil depends on edapho-climatic conditions (Silva et al., 1999). Within this context, the objective of this work was to study the persistence of herbicides during bad weather in the rainy season, by assessing their control over weeds in sugarcane.

Material and methods

The experiment was established in a commercial sugar cane plantation in its 3rd ratoon, Brazil; the cane variety was SP84-2025 and it was planted at a row spacing of 1.50 m. The soil type is Red Latosol, clay textural class with 49.9% clay, 36.6% sand and 13.5% silt.

The experimental design was a split-plot scheme, with the main-plots composed of 5 sugarcane rows of 5 m length, representing an area of 37.5 m², and the sub-plots by each row with 7.5 m² of area. Herbicides were assigned to the main plots: Untreated; imazapic (147 g/ha); imazapic (98 g/ha) + sulfentrazone (600 g/ha); sulfentrazone (800 g/ha); tebuthiuron (1000 g/ha);
amicarbazone (1400 g/ha); flumioxazin (125 g/ha); diuron (1066 g/ha) + hexazinone (134 g/ha) + imazapic (98 g/ha); amicarbazone (840 g/ha) + isoxaflutole (82.5 g/ha) + imazapic (98 g/ha) + isoxaflutole (85 g/ha). The weed species assigned to the sub-plots: *Ipomoea quamoclit*, *Ipomoea hederifolia*, *Merremia cissoides*, *Panicum maximum* and *Brachiaria decumbens*.

The seeds were sown in the interrows of each plot. During sowing, the cane straw was removed, the seeds were sown and the straw returned to the plots. The amount of seeds used was related to the germination test provided by the seed supplying company, so that each species provided 100 plants in the usable area of each main-plot. Herbicide application was performed in pre-emergence of the weed species and sugarcane with pressurised backpack equipment regulated at 200 kPa pressure and 250 L/ha spray volume.

At 70, 90 and 120 days after application (DAA), herbicide control over the weeds sown was assessed. The methodology used was assigning percentage scores to the coverage of weeds in the main-plot area, with 0 for no infestation and 100% for total infestation. Those scores were used for assigning control based on the calculation: \( ctr = 100\% \times \text{specific coverage} \).

The control scores were submitted to an analysis of variance according to the design proposed, and the averages were compared by Tukey test at 5% probability.

**Results and discussion**

The herbicides applied were possibly exposed over the straw for at least 15 days as, at the end of that period, an accumulation of 26.1 mm rain was recorded, possibly enough for herbicides to be leached through the straw layer and reach the soil. However, during that period, the 8.7°C oscillation between minimum and maximum temperature and the sunlight fell directly over the herbicide.

At 120 DAA, in addition to flumioxazin (125 g/ha), herbicides sulfentrazone (800 g/ha), tebuthiuron (1000 g/ha) and diuron (1066 g/ha) + hexazinone (134 g/ha) + imazapic (98 g/ha) also had an unsatisfactory level of control on the infesting weed communities. All species had lower controls by the herbicides when compared to those in the previous assessments, especially against the grasses.

However, when looking closer at the level of control by each herbicide treatment, it was observed that all herbicides provided unsatisfactory control for some species; herbicide imazapic (147 g/ha) had unsatisfactory control only for *B. decumbens*, imazapic (98 g/ha) + sulfentrazone (600 g/ha) on *M. cissoides*, sulfentrazone (800 g/ha) on *M. cissoides*, *P. maximum* and *B. decumbens*; tebuthiuron (100 g/ha) on *P. maximum* and *B. decumbens*; amicarbazone (1400 g/ha) on *I. quamoclit* and *B. decumbens*, flumioxazin (125 g/ha) unsatisfactory control for all the species, diuron (1066 g/ha) + hexazinone (134 g/ha) + imazapic (98 g/ha) on *I. quamoclit*, *M. cissoides* and *B. decumbens*; amicarbazone (840 g/ha) + isoxaflutole (82.5 g/ha) on *I. hederifolia* and imazapic (98 g/ha) + isoxaflutole (85 g/ha) on *I. quamoclit* and *B. decumbens*.

**Conclusions**

One hundred and twenty days after application, during which 698.7 mm rain were recorded with averages of 21.9 and 30.6°C as minimum and maximum temperature respectively, the herbicides that resisted the bad weather had an average control over the species studied in the following order: sufficient control: imazapic, amicarbazone, imazapic + sulfentrazone, imazapic + isoxaflutole amicarbazone + isoxaflutole; doubtful control: diuron + hexazinone + imazapic, tebuthiuron; insufficient control: sulfentrazone; and very bad control: flumioxazin.

**REFERENCES**


**PERSISTANCE DES HERBICIDES APPLIQUÉS À LA CANNE À SUCRE PENDANT LA SAISON DES PLUIES AU BRÉSIL**

Par


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**MOTS CLES:** Gestion de l’Enherbement, Contrôle de Pré-émergence, Paillis de Canne.

**Résumé**

CETTE ÉTUDE avait pour but de déterminer la persistance des herbicides dans le sol après une saison des pluies en évaluant les mauvaises herbes contrôlées dans des cultures de canne à sucre. Un dispositif en split-plot fut utilisé avec des parcelles principales de six lignes de canne (37.5 m²) et des sous parcelles d’une ligne de canne (7.5 m²). Des graines d’*Ipomoea quamoclit, Ipomoea hederifolia, Merremia cissoides, Panicum maximum* et *Brachiaria decumbens* furent semées dans les sous parcelles tandis que les parcelles principales étaient composées des dix traitements herbicides suivants: un témoin non traité, imazapic (147 g/ha), imazapic (98 g/ha) + sulfentrazone (600 g/ha), sulfentrazone (800 g/ha), tebuthiuron (1000 g/ha), amicarbazone (1400 g/ha), flumioxazin (125 g/ha), diuron (1066 g/ha) + hexazinone (134 g/ha) + imazapic (98 g/ha), amicarbazone (840 g/ha) + isoxaflutole (82.5 g/ha), imazapic (98 g/ha) + isoxaflutole (85 g/ha). Pendant les 120 jours suivant la pulvérisation, nous avons observé 698.7 mm de pluies, des températures moyennes minimum et maximum de 21.9°C et 30.6°C. Les herbicides qui ont le mieux persisté furent dans l’ordre décroissant: amicarbazone (avec un contrôle de 91.2% des mauvaises herbes), imazapic (90.8%), imazapic + sulfentrazone (89.6%), amicarbazone + isoxaflutole (89.2%), imazapic + isoxaflutole (85.6%), diuron + hexazinone + imazapic (84.4%), tebuthiuron (76%), sulfentrazone (70.8%), et enfin flumioxazin (19.2%).
PERMANENCIA DE HERBICIDAS APLICADOS A CANA DE AZUCAR DURANTE LA EPOCA LLUVIOSA EN BRASIL

Por


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PALABRAS CLAVE: Control de Malezas, Control Preemergente, Trash de Cana.

Resumen

El objetivo de la presente investigación era estudiar la permanencia de los herbicidas en el suelo después de la época lluviosa, evaluados de acuerdo al control de malezas en cana de azúcar. Se utilizó un diseño de parcelas divididas, con una parcela grande de seis surcos de cana (37.5 m$^2$) y una parcela pequeña de un surco (7.5 m$^2$). Se sembraron semillas de Ipomoea quamoclit, Ipomoea hederifolia, Merremia cissoides, Panicum maximum and Brachiaria decumbens en la parcela pequeña, mientras la parcela grande consistió en diez tratamientos con herbicidas, de la siguiente manera: un testigo sin aplicación, imazapic (147 g/ha), imazapic (98 g/ha) + sulfentrazone (600 g/ha), sulfentrazone (800 g/ha), tebuthiuron (1000 g/ha), amicarbazone (1400 g/ha), flumioxazin (125 g/ha), diuron (1066 g/ha) + hexazinone (134 g/ha) + imazapic (98 g/ha), amicarbazone (840 g/ha) + isoxaflutole (82.5 g/ha), imazapic (98 g/ha) + isoxaflutole (85 g/ha). Durante los 120 días después de la aplicación, se tuvo una precipitación de 698.7 mm, con temperatura mínima promedio de 21.9 y máxima promedio de 30.6°C. Los herbicidas que mejor soportaron estas condiciones presentaron un control satisfactorio de las especies bajo estudio, en el siguiente orden descendente: amicarbazone (91.2% de control), imazapic (90.8%), imazapic + sulfentrazone (89.6%), amicarbazone + isoxaflutole (89.2%), imazapic + isoxaflutole (85.6%), diuron + hexazinone + imazapic (84.4%), tebuthiuron (76%), sulfentrazone (70.8%), flumioxazin (19.2%).
PRODUCTIVITY OF UDULTS UNDER SUGARCANE AS INFLUENCED BY THE PROPERTIES OF THEIR TEXTURAL B HORIZON

By

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KEYWORDS: Sugarcane, Udults, Soil, Textural B Horizon.

Abstract

Studies to qualify the production environment have been undertaken to explore the productive potential of the soil, and consequently find the most favourable environment for sugarcane production. The surface and sub-surface characteristics of the soil, correlated with climate, allow the exploration of the genetic potential of sugarcane varieties. In the state of São Paulo (Brazil), there are extensive areas of Udult with sugarcane plantations. However, these Udults possess different water availabilities due to differences in clay content between the A and B horizons and the position where the textural B horizon (Bt) begins in the soil profile, thus influencing sugarcane productivity. Udults with Bt horizon beginning at 40, 60, or 80 cm were analysed. Soil samples were obtained in 0–20 cm, 20–40 cm and in the Bt horizon for determination of physical properties, such as clay content and available water capacity. The correlation of the productivity data with morphological characteristics such as the textural gradient of the Udults led to the conclusion that Udults with Bt horizon beginning at around 40 cm depth showed better conditions for water and nutrient absorption by the roots and consequently better sugarcane productivity.

Introduction

The production environment can be qualified by associating soil classification with climate information. Pedological characteristics can be used to obtain productivity increases of sugarcane through proper and rational soil exploration.

Prado (2007) defines the production environment as an association of surface and subsurface soil characteristics correlated with regional climate. The state of São Paulo accounts for a large amount of sugarcane production in Brazil and large areas are used.

Regarding soils with high occurrence, extensive areas of Udults (EMBRAPA, 2006) are used for sugarcane production. The Udults have morphological characteristics, namely an elevated textural gradient between the surface A horizon and the subsurface textural B horizon (Bt), and pedological characteristics, namely the position where the Bt horizon begins in the soil profile, that affect the water flux and storage in the soil.

This creates a wide variety of production environments in the same region. This work shows that the Udult heterogeneity, such as the textural differences between A and Bt horizons and the initial position of the Bt soil horizon, causes differences in the production environments of sugarcane.

Material and methods

The productivity data were acquired from sugarcane industries in the regions of Catanduva, Quatá, Porto Ferreira and Itapira, all located in the state of São Paulo. The soils studied were
Udults, with Bt horizon beginning at 40, 60 or 80 cm. Samples were obtained for granulometric analysis and determination of available water capacity (AWC) at 0–20 cm, 20–40 cm depth and in Bt horizon, which occurs at variable depth in the soil profile.

Results and discussion

Table 1 shows the productivity of the Udults in the four regions under study. Sugarcane productivity was observed to be lower where the Bt horizon starts at a greater depth, as described by Prado et al. (2008).

This indicates that Udults with Bt horizon beginning at about 40 cm showed better conditions for water and nutrient absorption by roots and consequently better productivity for sugarcane.

In the four regions studied, Udults with Bt horizon beginning around 40 cm showed the highest productivities, independent of the subsurface chemical condition.

Table 1—Sugarcane productivities (average of 5 analyses) in Udults with Bt horizon starting at different depths.

<table>
<thead>
<tr>
<th>Region</th>
<th>Porto Ferreira</th>
<th>Quatá</th>
<th>Itapira</th>
<th>Catanduva</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth of the B horizon starting (cm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>96.0</td>
<td>79.18</td>
<td>88.26</td>
<td>111.5</td>
</tr>
<tr>
<td>60</td>
<td>82.0</td>
<td>70.30</td>
<td>79.5</td>
<td>90.0</td>
</tr>
<tr>
<td>80</td>
<td>76.0</td>
<td>66.51</td>
<td>73.8</td>
<td>74.7</td>
</tr>
</tbody>
</table>

In Table 2, results of the granulometric analysis show that soil water storage is better where the difference in clay percentage between A and Bt horizons is larger. The high textural gradient in the Udults was thus one of the responsible factors for the highest sugarcane productivities.

Table 2—Available water capacity of Ultisols (40 cm of A horizon and 60 cm of the Bt horizon) from 4 regions studied, considering the content of clay.

<table>
<thead>
<tr>
<th>Region</th>
<th>A Horizon</th>
<th>AWC – A Horizon</th>
<th>Bt Horizon</th>
<th>AWC – Bt Horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Clay</td>
<td>(L of water/cm of soil)</td>
<td>% Clay</td>
<td>(L of water/cm of soil)</td>
<td></td>
</tr>
<tr>
<td>Catanduva</td>
<td>16</td>
<td>0.12</td>
<td>42</td>
<td>0.60</td>
</tr>
<tr>
<td>Itapira</td>
<td>18</td>
<td>0.14</td>
<td>35</td>
<td>0.52</td>
</tr>
<tr>
<td>Quatá</td>
<td>17</td>
<td>0.13</td>
<td>30</td>
<td>0.45</td>
</tr>
<tr>
<td>Porto Ferreira</td>
<td>19</td>
<td>0.15</td>
<td>37</td>
<td>0.55</td>
</tr>
</tbody>
</table>

With respect to AWC values obtained in all Udults (Table 3), those with Bt horizon beginning at around 40 cm had the highest AWC value, assuming a rooting depth of 1 metre.

Table 3—Analysis of AWC in the Bt horizons of the Udults.

<table>
<thead>
<tr>
<th>Bt horizon start (cm)</th>
<th>CC* (% volume)</th>
<th>PWP* (% volume)</th>
<th>H* (cm)</th>
<th>AWC (L of water/cm of soil)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>15</td>
<td>5</td>
<td>60</td>
<td>0.60</td>
</tr>
<tr>
<td>60</td>
<td>14.4</td>
<td>4.6</td>
<td>40</td>
<td>0.39</td>
</tr>
<tr>
<td>80</td>
<td>13.8</td>
<td>4.8</td>
<td>20</td>
<td>0.18</td>
</tr>
</tbody>
</table>

*CC = field capacity
*PWP = permanent wilting point
*H = depth of Bt horizon
*AWC = L of water/cm of Bt horizon considering the depth of 100 cm

Conclusions

The Udults with Bt horizon beginning at around 40 cm and with a high percentage of clay in the beginning of this horizon had higher productivity, due to the elevated water retention and availability in the soil profile.
Through correlation of productivity data with morphological and pedological characteristics of the Udults, it was possible to conclude that soils with Bt horizon beginning at 40 cm had an environment that was more suitable for production as they allowed better water and nutrient absorption by the roots and, consequently had the highest sugarcane productivity.

REFERENCES


PRODUCTIVITE DES UDULTS SOUS CANNE A SUCRE SELON LES PROPRIETES DE LEUR HORIZON TEXTURAL B

Par

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MOTS-CLES: Canne à Sucre, Udults, Sol, Horizon Textural B.

Résumé

Des études de caractérisation de la production environnementale ont été entreprises afin d’inventorier le potentiel productif du sol, et donc de trouver l’environnement le plus favorable pour la production de canne à sucre. Les caractéristiques surfaciques et pédologiques du sol, corréllées au climat, permettent d’explorer le potentiel génétique des variétés de canne à sucre. Dans l’état de São Paulo (Brésil), il existe des surfaces importantes d’Udults cultivées en canne à sucre. Cependant, ces Udults possèdent des disponibilités différentes en eau liées aux différentes teneurs en argile entre les horizons A et B et à la position où l’horizon textural B (Bt) commence dans le profil de sol, influençant ainsi la productivité de la canne à sucre. Des Udults avec des horizons Bt commençant à 40, 60 et 80 cm ont été analysés. Des échantillons de sol ont été prélévés entre 0–20, 20–40 cm et dans l’horizon Bt afin de déterminer les propriétés physiques, telles que la teneur en argile et la réserve en eau disponible. La corrélation entre la productivité et les caractéristiques morphologiques des Udults telles que leur gradient textural montre que les Udults avec un horizon Bt à environ 40 cm de profondeur présentent les meilleures conditions d’absorption en eau et éléments minéraux pour les racines et par conséquent la meilleure productivité en canne à sucre.
PRODUCTIVIDAD DE UDULTS BAJO EL CULTIVO DE CAÑA DE AZÚCAR, INFLUENCIADOS POR LAS PROPIEDADES DE SU HORIZONTE B TEXTURAL

Por

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PALABRAS CLAVE: caña de azúcar, Udults, suelo, horizonte B textural

Resumen

Se han realizado estudios para calificar el ambiente de producción con el fin de explorar el potencial productivo del suelo y, consecuentemente, encontrar el ambiente más favorable para la producción de la caña de azúcar. Las características de la superficie y sub-superficie del suelo correlacionadas con el clima permiten la exploración del potencial genético de las variedades de caña de azúcar. En el estado de São Paulo (Brasil) hay áreas extensivas de Udults con plantaciones de caña de azúcar. Sin embargo, estos Udults poseen diferentes disponibilidades de agua, debido a diferencias en el contenido de arcillas entre los horizontes A y B, y la posición en que comienza el horizonte B textural (Bt) en el perfil, lo cual influye la productividad de la caña de azúcar. Se analizaron Udults con horizonte Bt a los 40, 60 y 80 cm. Se obtuvo muestras de suelo de 0–20 cm, 20–40 cm y del horizonte Bt para determinar propiedades físicas tales como contenido de arcilla y capacidad de disponibilidad de agua. La correlación de los datos de productividad con características morfológicas como el gradiente textural de los Udults, condujo a concluir que los Udults con un horizonte Bt que comienza alrededor de los 40 cm de profundidad, muestran mejores condiciones para la absorción de agua y nutrientes por las raíces y, consecuentemente, una mejor productividad de caña de azúcar.
SILICON AMENDMENT IN THE PRODUCTIVITY OF FOUR SUGARCANE VARIETIES IN BRAZIL

By
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KEYWORDS: Silicon, Sugarcane
Productivity, Economy, Variety.

Abstract
SILICON is a beneficial element for some crops. The low rates of available silicon in tropical soils, together with the large amount of silicon extracted by sugarcane, emphasises the importance of this work which reports on the responses of four sugarcane varieties to excoriates of metallurgy applied as a silicon source. The soil in the experiment was an Oxisol, medium texture, previously cultivated with pasture and it has a low level of soluble silicon (less than 3 ug/cm³). A split plot trial comprised four sugarcane varieties as the main plots: RB867515—high productivity; SP81-3250—rich and high productivity; RB72454 and SP83-2847—wide adaptability varieties. The sub plots were two treatments comprising a control (no silicon) and a plot receiving 940 kg/ha of Agrosilício containing 23% SiO₂. The fertilisers were applied at the bottom of the furrows at planting. The measured parameters were fibre, purity, Pol, reducing sugars (AR) and total recoverable sugars (ATR), and cane yield (t/ha). The economic analysis was conducted on plant cane. We observed different productivity for varieties due to silicon application in the first harvest. The varieties RB72454 and SP83-2847 were more responsive, and there were economic gains from silicon application. The economical gains in the second period of harvest were lower, with no statistical differences between treatments.

Introduction
In the past 10 years, Brazil has become the world's leading exporter of sugar, accounting for 30% of world exports of the product. Brazilian ethanol produced from sugarcane is both more economical and more efficient in terms of carbon dioxide balance (GHG emissions) than gasoline.

This aspect is reflected in the fact that Brazil is now responsible for half of world exports of the product.

There has been major expansion of sugarcane planted areas in the west of São Paulo, Minas Gerais, Mato Grosso, Mato Grosso do Sul and Goias states. Many of those areas, for example the west of São Paulo and Goias states, are usually deficient in Si with marginal soils that are sandy and with low fertility.

Although silicon is not considered an essential element for plant nutrition, scientific research has showed its involvement in structural, physiologic and biochemical aspects.

Some benefits have been ascribed to silicon application, such as: more tolerance to water stress, resistance to lodging in rice and cane, productivity increase and improvement in the product quality. Lima Filho et al. (1999) emphasised the need for silicon in tropical and subtropical soils. In general, tropical soils have lost available silicon by intensive leaching due to...
climatic conditions and some agricultural practices like intensive cultivation and continuous monoculture.

There is a lack of information in the literature concerning differences between sugarcane varieties in response to silicon application.

Sugarcane uptakes more silicon than potassium and nitrogen. Therefore, the low rate of available silicon in verified (or controlled) plants in Oxisols, plus the great silicon extraction accumulated by sugarcane biomass, emphasise the objectives of this paper.

Our main objective was to verify the response of four different sugarcane varieties in productivity, Pol, purity, reducing sugars (AR) and total recoverable sugars (ATR).

**Material and methods**

Field trials were initiated in May, 2007 at Moema sugar-mill production area, in the district of Orindiuva, São Paulo, Brazil, on an Oxisol of medium texture, 3 mmolc/dm³ of soluble silicon to study the productivity of sugarcane varieties following the application of silicon fertiliser in two planting seasons namely July and November 2008.

The experiment used a split plot design with four main treatments, namely sugarcane varieties RB867515, RB72454, SP81-3250 and SP83-2847.

The sub-plot treatment comprised the control (without silicon) and the treated plot receiving 940 kg/ha of ‘Agrosilício’ that is a silicon fertiliser produced by EXCELL company containing 23% of total silicon and 43% of soluble silicon.

Silicon fertiliser was applied in the planting furrow. In each plot, 500 kg/ha of 13-20-25 (N-P₂O₅-K₂O) was applied in the furrow.

The plots were replicated four times in a randomised block design. Each sub plot consisted of 10 cane rows 8 m long and spaced at 1.40 m.

The plots were weighed with a dynamometer to determine cane yield (t/ha). Pol, fibre, purity, reducing sugars (AR) and total recoverable sugars (ATR) were determined in ten stalks collected in each plot according to CONSECANA, (1999).

We also calculated the economic revenue (mean ATR/ha) = mean productivity of the varieties-treatment with silicon – mean productivity of the varieties-treatment without silicon; productivity (%) = (mean productivity of the varieties-treatment with silicon/mean productivity of the varieties-treatment without silicon * 100; Relative revenue for the productivity earnings = productivity * ATR (month reference August of 2008 = U$0.0999 and month reference November of 2008 = U$0.1206); cost fertilisers = function of the applied dose and adopted product. Liquidate relative = relative revenue – cost of the fertilisers (U$40.00/ha).

Statistical analyses of variance were performed using SAS software, and means were compared with Tukey’s test with P = 0.05%. The graphs were produced with the Office/Excel software.

**Results and discussion**

In Table 1 we show the results of the first evaluation time. The varieties showed differences such as: Pol cane, purity, reducing sugars (AR) and total recoverable sugars (ATR).

The varieties RB72454 and SP83-2847 are considered varieties with wide adaptability to low soil fertility and restrictive conditions of climate. RB867515 and SP81-3250 require more nutrients; however, there was no statistical difference in yield between varieties. Silicon promoted just a few changes in Pol% and ATR. Silicon application promoted increments in stalk productivity near 5 t/ha (132.61-127.36).

In the second harvest period (Table 2), which differed from the first period because there were no constraints in water and thermal climate parameters, there was no response for silicon application in stalk yield.
Increases in productivity were observed for variety RB867515 in the second harvest, but variety SP81-3250 maintained the same productivity in both harvests. These varieties should be harvested in the second harvest period. However, the varieties RB72454 and SP83-2847 should be harvested in the middle of the harvest period. There was no interaction between variety and silicon.

Table 1—Variance analysis and comparison among averages for Pol, fibre, purity, reducing sugars (AR), total recoverable sugars (ATR), and stalks productivity harvested on July 2008.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Fibre</th>
<th>Purity</th>
<th>Pol cane</th>
<th>AR</th>
<th>ATR</th>
<th>TCH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>%</td>
<td>kg/t cane</td>
<td>t/ha</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variety (V)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RB867515</td>
<td>12.29 a</td>
<td>15.85 b</td>
<td>90.39 a</td>
<td>0.54 b</td>
<td>155.47 ab</td>
<td>132.73 a</td>
</tr>
<tr>
<td>RB72454</td>
<td>10.32 a</td>
<td>16.47 a</td>
<td>89.93 ab</td>
<td>0.56 ab</td>
<td>161.35 a</td>
<td>128.92 a</td>
</tr>
<tr>
<td>SP81-3250</td>
<td>12.73 a</td>
<td>16.03 ab</td>
<td>88.47 b</td>
<td>0.61 a</td>
<td>157.29 ab</td>
<td>129.78 a</td>
</tr>
<tr>
<td>SP83-2847</td>
<td>12.25 a</td>
<td>15.45 b</td>
<td>88.87 ab</td>
<td>0.59 ab</td>
<td>151.71 b</td>
<td>128.92 a</td>
</tr>
<tr>
<td>Silicon (S)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(-Si) without silicon</td>
<td>11.84 a</td>
<td>15.72 b</td>
<td>89.02 a</td>
<td>0.59 a</td>
<td>154.29 b</td>
<td>127.36 b</td>
</tr>
<tr>
<td>(+Si) with silicon</td>
<td>11.95 a</td>
<td>16.20 a</td>
<td>89.77 a</td>
<td>0.56 a</td>
<td>158.62 a</td>
<td>132.61 a</td>
</tr>
<tr>
<td>V X S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RB867515 (–Si)</td>
<td>12.55</td>
<td>15.71</td>
<td>90.08</td>
<td>0.55</td>
<td>153.88</td>
<td>128.62</td>
</tr>
<tr>
<td>RB867515 (+Si)</td>
<td>12.03</td>
<td>16.06</td>
<td>90.52</td>
<td>0.54</td>
<td>157.07</td>
<td>136.84</td>
</tr>
<tr>
<td>RB72454 (–Si)</td>
<td>9.47</td>
<td>16.46</td>
<td>89.77</td>
<td>0.56</td>
<td>161.32</td>
<td>124.92</td>
</tr>
<tr>
<td>RB72454 (+Si)</td>
<td>11.16</td>
<td>16.48</td>
<td>90.90</td>
<td>0.55</td>
<td>161.34</td>
<td>132.18</td>
</tr>
<tr>
<td>SP81-3250 (–Si)</td>
<td>12.97</td>
<td>15.65</td>
<td>87.62</td>
<td>0.64</td>
<td>153.81</td>
<td>127.72</td>
</tr>
<tr>
<td>SP81-3250 (+Si)</td>
<td>12.50</td>
<td>16.42</td>
<td>89.34</td>
<td>0.58</td>
<td>160.76</td>
<td>131.84</td>
</tr>
<tr>
<td>SP83-2847 (–Si)</td>
<td>12.37</td>
<td>15.06</td>
<td>88.61</td>
<td>0.60</td>
<td>148.11</td>
<td>128.17</td>
</tr>
<tr>
<td>SP83-2847 (+Si)</td>
<td>12.13</td>
<td>15.84</td>
<td>89.14</td>
<td>0.58</td>
<td>155.31</td>
<td>129.67</td>
</tr>
</tbody>
</table>

| F value |       |        |          |     |     |     |
| Variety (V) | 2.50 ns | 3.79 * | 3.84* | 3.77* | 3.95* | 1.26 ns |
| Silicon (S) | 0.03 ns | 4.85* | 2.93* | 2.85 ns | 4.62* | 9.64** |
| V vs S | 0.60 ns | 0.70 ns | 0.56 ns | 0.50 ns | 0.72 ns | 0.81 ns |
| Blocks (B) | 0.72 ns | 1.72 ns | 1.26 ns | 1.36 ns | 2.00 ns | 1.71 ns |
| CV (%) | 16.19 | 3.85 | 1.39 | 7.47 | 3.64 | 3.68 |
| MSE (%) | 1.93 | 0.61 | 1.24 | 0.04 | 5.70 | 4.79 |
| General mean (T) | 11.90 | 15.97 | 89.39 | 0.58 | 156.45 | 129.99 |
| msd (V) | 2.69 | 0.86 | 1.23 | 0.06 | 7.94 | 6.67 |
| msd (S) | 1.42 | 0.45 | 0.91 | 0.03 | 4.19 | 3.52 |

AR: reducing sugar. ATR: recovered total sugar; TCH: stalks tonnes per hectare. Averages following by different letters differ are significantly different by Tukey’s test. * and **: significant for p = 5 and 1%, respectively. Ns: not significant.
Table 2—Variance analysis and comparison among averages for Pol, fibre, purity, reducing sugars (AR), total recoverable sugars (ATR), and stalks productivity harvested on November 2008.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Fibre</th>
<th>Purity</th>
<th>Pol cane</th>
<th>AR</th>
<th>ATR</th>
<th>TCH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>kg/t cane</td>
<td>t/ha</td>
</tr>
<tr>
<td>Variety (V)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RB867515</td>
<td>11.57 a</td>
<td>16.10 a</td>
<td>89.64 a</td>
<td>0.57 b</td>
<td>157.76 a</td>
<td>134.17 a</td>
</tr>
<tr>
<td>RB72454</td>
<td>11.52 a</td>
<td>16.04 a</td>
<td>90.26 a</td>
<td>0.55 b</td>
<td>157.05 a</td>
<td>125.56 b</td>
</tr>
<tr>
<td>SP81-3250</td>
<td>12.65 a</td>
<td>15.19 a</td>
<td>88.85 a</td>
<td>0.59 b</td>
<td>149.16 a</td>
<td>129.55 ab</td>
</tr>
<tr>
<td>SP83-2847</td>
<td>11.77 a</td>
<td>13.45 b</td>
<td>863.10 a</td>
<td>0.79 a</td>
<td>134.27 b</td>
<td>124.05 b</td>
</tr>
<tr>
<td>Silicon (S)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(–Si) without silicon</td>
<td>11.78 a</td>
<td>15.12 a</td>
<td>87.76 a</td>
<td>0.63 a</td>
<td>148.89 a</td>
<td>127.06 a</td>
</tr>
<tr>
<td>(+Si) with silicon</td>
<td>11.86 a</td>
<td>15.27 a</td>
<td>88.17 a</td>
<td>0.62 a</td>
<td>150.23 a</td>
<td>129.65 a</td>
</tr>
<tr>
<td>V X S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RB867515 (–Si)</td>
<td>11.28</td>
<td>16.25</td>
<td>89.23</td>
<td>0.58</td>
<td>159.30</td>
<td>132.67</td>
</tr>
<tr>
<td>RB867515 (+Si)</td>
<td>11.85</td>
<td>15.95</td>
<td>90.04</td>
<td>0.55</td>
<td>156.22</td>
<td>135.67</td>
</tr>
<tr>
<td>RB72454 (–Si)</td>
<td>11.53</td>
<td>15.67</td>
<td>89.40</td>
<td>0.58</td>
<td>153.67</td>
<td>124.61</td>
</tr>
<tr>
<td>RB72454 (+Si)</td>
<td>11.51</td>
<td>16.42</td>
<td>91.13</td>
<td>0.52</td>
<td>160.43</td>
<td>126.72</td>
</tr>
<tr>
<td>SP81-3250 (–Si)</td>
<td>12.61</td>
<td>15.26</td>
<td>89.53</td>
<td>0.57</td>
<td>149.67</td>
<td>127.80</td>
</tr>
<tr>
<td>SP81-3250 (+Si)</td>
<td>12.70</td>
<td>15.12</td>
<td>88.17</td>
<td>0.62</td>
<td>148.70</td>
<td>131.31</td>
</tr>
<tr>
<td>SP83-2847 (–Si)</td>
<td>11.71</td>
<td>13.31</td>
<td>82.86</td>
<td>0.80</td>
<td>132.97</td>
<td>123.18</td>
</tr>
<tr>
<td>SP83-2847 (+Si)</td>
<td>11.42</td>
<td>13.60</td>
<td>83.34</td>
<td>0.78</td>
<td>135.57</td>
<td>124.93</td>
</tr>
</tbody>
</table>

F value

| Variety (V) | 2.88 ns | 23.28 ** | 18.09** | 17.91** | 21.24** | 5.25** |
| Silicon (S) | 0.07 ns | 0.35 ns  | 0.28 ns  | 0.29 ns  | 0.58 ns  | 0.20 ns |
| V vs S      | 0.30 ns | 0.85 ns  | 0.70 ns  | 0.68 ns  | 0.49 ns  | 0.99 ns |
| Blocos (B)  | 2.43 ns | 3.52*    | 2.40 ns  | 2.36 ns  | 0.04 ns  | 0.87 ns |
| CV (%)      | 7.80    | 4.76     | 2.48     | 12.08    | 4.48     | 4.33    |
| MSE (%)     | 0.92    | 0.72     | 2.19     | 0.08     | 6.70     | 5.52    |
| General mean (T) | 11.82  | 15.20    | 87.96    | 0.62    | 149.56   | 128.36  |
| msd (V)     | 1.29    | 1.01     | 3.05     | 0.11    | 9.33     | 7.76    |
| msd (S)     | 0.68    | 0.53     | 1.61     | 0.05    | 4.92     | 4.09    |

AR: reducing sugar; ATR: recovered total sugar; TCH: stalks tonnes per hectare. Averages following by different letters are significantly different by Tukey’s test. * and **: significant for p= 5 and 1%, respectively. ns: not significant.

Table 3 shows the calculations of economical income concerning the use of silicon. The largest incomes as well as the relative balances were positive for silicon application in the first period of harvest. However, in the second harvest period, the incomes were not so impressive, resulting in little economical return per hectare. As an example, the agricultural area in a sugar mill is around 20 000 hectares.

In this case, it is possible with use of silicon to obtain profits of US$548 400.00 (20 000 hectares multiplied by US$27.42 with silicon, Table 3).
Table 3—Absolute contributions and relative balances obtained for varieties vs silicon and silicon in the experiment harvested in August (Time 1) and November (Time 2).

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Productivity Average ATR/ha</th>
<th>Productivity ATR/ha</th>
<th>Productivity (%)</th>
<th>Balance relative US$/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RB867515 (–Si)</td>
<td>19 789</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>RB867515 (+Si)</td>
<td>21 452</td>
<td>1663</td>
<td>8.40</td>
<td>126.17</td>
</tr>
<tr>
<td>RB72454 (–Si)</td>
<td>20 156</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>RB72454 (+Si)</td>
<td>21 328</td>
<td>1172</td>
<td>5.81</td>
<td>98.89</td>
</tr>
<tr>
<td>SP81-3250 (–Si)</td>
<td>19 646</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>SP81-3250 (+Si)</td>
<td>21 205</td>
<td>1559</td>
<td>7.94</td>
<td>144.72</td>
</tr>
<tr>
<td>SP83-2847 (–Si)</td>
<td>19 007</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>SP83-2847 (+Si)</td>
<td>20 134</td>
<td>1127</td>
<td>5.93</td>
<td>90.76</td>
</tr>
<tr>
<td>Silicon (average)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(–Si) – without silicon</td>
<td>19 649</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>(+Si) – with silicon</td>
<td>21 030</td>
<td>1381</td>
<td>7.03</td>
<td>97.99</td>
</tr>
<tr>
<td><strong>Time 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RB867515 (–Si)</td>
<td>21 130</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>RB867515 (+Si)</td>
<td>21 212</td>
<td>82</td>
<td>0.39</td>
<td>– 30.11</td>
</tr>
<tr>
<td>RB72454 (–Si)</td>
<td>19 162</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>RB72454 (+Si)</td>
<td>20 327</td>
<td>1165</td>
<td>6.08</td>
<td>100.50</td>
</tr>
<tr>
<td>SP81-3250 (–Si)</td>
<td>19 115</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>SP81-3250 (+Si)</td>
<td>19 529</td>
<td>414</td>
<td>2.17</td>
<td>9.93</td>
</tr>
<tr>
<td>SP83-2847 (–Si)</td>
<td>16 401</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>SP83-2847 (+Si)</td>
<td>16 981</td>
<td>580</td>
<td>3.54</td>
<td>29.95</td>
</tr>
<tr>
<td>Silicon (average)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(–Si) – without silicon</td>
<td>18 953</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>(+Si) – with silicon</td>
<td>19 512</td>
<td>559</td>
<td>2.95</td>
<td>27.42</td>
</tr>
</tbody>
</table>

(–Si) and (+Si): without silicon and with silicon, respectively.

Silicon use provided gains in productivity for all varieties in this experiment. The increase was around 7% in the first period of harvest and of 3% in the second time. The varieties RB867515 and SP81-3250 were more responsive in the first evaluation time, showing 8.40 and 7.90% respectively in ATR gains.

For the second period of harvest, the varieties RB72454 and SP83-2847 were more responsive showing 6.08 and 3.54% respectively in ATR gains.

REFERENCES


EFFET D’UN AMENDEMENT A BASE DE SILICIUM SUR LA PRODUCTIVITE
DE QUATRE VARIETES DE CANNE A SUCRE AU BRESIL

By
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MOTS CLES: Silicium, productivité de la canne à sucre, économie, variété

Résumé
Le silicium est un élément bénéfique pour de nombreuses cultures. Les faibles teneurs en silicium disponible dans les sols tropicaux associées aux grandes quantités de silicium mobilisées par la canne à sucre, accentuent l’importance de cette étude qui relate la réponse de quatre variétés de canne à sucre à des scorces de métallurgie appliquées comme source de silicium. Le sol de l’essai était un Oxisol de texture moyenne, avec un précédent pâturage et ayant une faible teneur en silicium soluble (moins de 3 μg/cm³). Un essai en split plot comprenait quatre variétés de canne à sucre comme parcelles principales, RB867515, productivité élevée; SP81-3250 – riche et productivité élevée; RB72454 – large adaptabilité; et SP83-2847 – rustique. Les sous parcelles comprenaient un témoin sans silicium et un traitement recevant 940 kg/ha d’Agrosilício contenant 23% de SiO₂. Les engrais ont été épandus au fond du sillon à la plantation. Les paramètres mesurés furent la fibre, la pureté, le Pol, les sucres réducteurs (AR), les sucres totaux extractibles (ATR) et le rendement (t/ha). L’analyse économique fut réalisée sur la canne plantée. Selon les doses de silicium, différentes productivités ont été observées pour les variétés de canne. Les variétés RB72454 et SP83-2847 ont montré les réponses les plus élevées avec des gains économiques dus à l’application de silicium. Les gains économiques sur la seconde récolte furent plus faibles avec aucune différence statistique entre traitements.
ENMIENDA DE SILICIO EN LA PRODUCTIVIDAD DE CUATRO VARIEDADES DE CANA DE AZUCAR EN BRASIL

Por

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PALABRAS CLAVE: Silicio, Productividad de Cana de Azúcar, Economía, Variedad.

Resumen
El silicio es un elemento benéfico para algunos cultivos. El bajo contenido de silicio en los suelos tropicales, aunado a la gran cantidad de silicio que la caña de azúcar extrae, enfatiza la importancia de este trabajo, que reporta las respuestas de cuatro variedades de caña de azúcar a la aplicación de residuos de metalurgia como fuente de silicio. El suelo en que se plantó el experimento era un Oxisol, de textura media, previamente cultivado con pasto y con bajo nivel de silicio (menos de 3 ug/cm³). Se utilizó un diseño de parcelas divididas con las variedades de caña como parcela grande- RB867515 – productividad alta; SP81-3250 – productividad alta y rica; RB72454 – amplia adaptabilidad y SP83-2847 – una variedad rustica. Las parcelas pequeñas fueron dos tratamientos: un testigo (sin silicio) y una parcela donde se aplicó 940 kg/ha de Agrosilicio que contiene 23% SiO₂. Los fertilizantes se aplicaron en el fondo del surco en el momento de la siembra. Los parámetros evaluados fueron fibra, pureza, Pol, azúcares reductores (AR) y total de azúcar recuperable (ATR) y rendimiento de cana (ton/ha). Se realizó un análisis económico en soca. Se observó diferencia en la productividad de las variedades debidas a la aplicación de silicio en la primera cosecha. Las variedades RB72-2454 y SP83-2847 tuvieron mejor respuesta y presentaron ganancias económicas con la aplicación de silicio. Las ganancias económicas en la segunda cosecha fueron menores, sin diferencia estadística entre tratamientos.
THE DSSAT4.5 CANEGRO MODEL: A USEFUL DECISION SUPPORT TOOL FOR RESEARCH AND MANAGEMENT OF SUGARCANE PRODUCTION

By

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KEYWORDS: Crop Model, Biomass, Sucrose Mass, Leaf Area Index, Simulation.

Abstract

THE NEW DSSATv4.5 Canegro model allows users to combine the latest advances in sugarcane modelling with the latest DSSAT functionality to address production and research problems. The objectives of this poster are to (1) describe the main features of the model, (2) report on its accuracy of simulating biomass, cane and sucrose yields in different parts of world, and (3) highlight potential applications in sugarcane research and management. The model uses daily weather data to simulate canopy development, interception of radiation, biomass accumulation and partitioning. It simulates the effect of water stress and lodging on photosynthesis, growth and sucrose storage. Eighteen cultivar parameters are used to simulate genetic control of crop response to environmental factors. Simulated green leaf area index, aboveground biomass, stalk mass and sucrose mass were compared with observed data from Australia, Brazil, South Africa, Thailand and Zimbabwe. The model performed remarkably well for these widely different cropping situations and cultivar types. In some cases, the simulated biomass accumulation rates declined too rapidly in winter leading to an underestimation of yields. This needs further investigation. The DSSATv4.5 Canegro model is now easily accessible and may be applied, after thorough testing, to support research and management world-wide.

Introduction

The new DSSAT v4.5 Canegro model allows users to combine the latest advances in sugarcane modelling with the latest DSSAT (Jones et al., 2003) functionality to address production and research problems.

The objectives of this poster are to (1) describe the main features of the model, (2) report on its accuracy of simulating biomass, cane and sucrose yields in different parts of world, and (3) highlight potential applications in sugarcane research and management.

Model description

The DSSAT v4.5 Canegro plant module (Singels et al., 2008) uses soil properties, weather data, management inputs and genetic parameters to simulate the daily growth and development of sugarcane crops.
The duration of phenological phases (germination, tiller production, tiller senescence and stalk elongation) are simulated using the thermal time (TT) concept.

Tiller population and numbers of green and dead leaves on the primary tiller are calculated using TT. The product of leaf size, tiller population and leaf number provides total and green leaf area index (GLAI).

Interception of photosynthetically active radiation is calculated using Beer’s law. Biomass accumulation is calculated following the radiation use efficiency approach but also accounting for respiration.

Partitioning of biomass to different plant components, including stalk sucrose, is calculated using a source-sink approach and accounts for physiological age, temperature and water stress.

Water stress is calculated following the CERES approach (Jones and Kiniry, 1986) of process-specific soil water deficit factors.

Water stress affects rates of transpiration, photosynthesis, growth and sucrose storage. The model uses 18 cultivar parameters to simulate genetic control of crop growth and development to environmental factors.

**Model testing**

The model was tested using experimental data from Australia, Brazil, South Africa, Thailand and Zimbabwe (see Table 1).

The model was calibrated for cultivars other than NCo376 by adjusting the values of some cultivar parameters so that simulations of phenological, tiller and leaf development and of biomass partitioning followed observations closer.

Simulation accuracy was quantified using the root mean square of the deviations between simulated and observed values, expressed as a percentage of the mean observed value (RMSE).

Visual comparisons of simulations with experimental data showed that the model performed remarkably well for most of these widely different cropping situations and cultivar types.

RMSEs for GLAI, biomass, stalk dry mass and sucrose mass ranged from 11 to 45, 14 to 26, 13 to 34 and 7 to 34% respectively (see Table 1).

The large errors are ascribed to incomplete cultivar calibration or to apparent model shortcomings.

The study highlighted areas that may require refinement:

- The simulation of tiller appearance and senescence does not adequately account for the dynamic effects of planting density and radiation transmission through the canopy. This leads to inaccurate predictions of GLAI at times.

- Observations from several data sets (South Africa, Australia, Brazil) suggest that the simulated reduction in the rate of biomass accumulation due to decreased temperature is too drastic. Further investigation into this aspect is required.

**Model applications**

Sugarcane crop models have many applications in research and management of sugarcane production. These include:

1. climate change impact studies (Marin et al. 2009);
2. exploring ideotypes for given environments;
3. forecasting crop yield and quality (Bezuidenhout and Singels, 2007); and
4. supporting irrigation management (Singels and Smith, 2006).

The inclusion of an up-to-date Canegro model into the DSSATv4.5 package makes sugarcane modelling more easily accessible and should enhance sugarcane research and management. However, local testing is necessary before the model can be applied with confidence.
<table>
<thead>
<tr>
<th>Site</th>
<th>Soil depth, texture class</th>
<th>Dryland/Irrigated</th>
<th>Cultivars</th>
<th>Start date (month, year)</th>
<th>RMSE GLAI</th>
<th>RMSE Biomass</th>
<th>RMSE Stalk mass</th>
<th>RMSE Sucrose mass</th>
<th>Source of data</th>
</tr>
</thead>
<tbody>
<tr>
<td>La Mercy, South Africa, 29°34’S, 30°8’E</td>
<td>1.65m, sandy clay loam</td>
<td>Dryland</td>
<td>NCo376</td>
<td>Jun89, Aug89, Oct89, Dec89, Feb90, Apr90, Jun90, Aug90</td>
<td>26.5</td>
<td>14.6</td>
<td>27.5</td>
<td>31.2</td>
<td>Inman-Bamber, 1994</td>
</tr>
<tr>
<td>Pongola, South Africa, 27°24’S, 31°35’E</td>
<td>4m sandy clay loam</td>
<td>Irrigated</td>
<td>NCo376</td>
<td>Dec68, Feb69, Apr69, Jun69, Jul69, Sep69, Nov69, Jan70</td>
<td>NA</td>
<td>NA</td>
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<td>19.7</td>
<td>Rostron, 1972</td>
</tr>
<tr>
<td>Mount Edgecombe, South Africa, 29°42’S, 31°2’E</td>
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<td>Oct03, Apr04</td>
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<td>34.0</td>
<td>Singels and Smit (2008)</td>
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<td>Oct03, Apr04</td>
<td>30.1</td>
<td>15.2</td>
<td>13.2</td>
<td>20.3</td>
<td>Singels and Smit (2008)</td>
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<td>Q138, Q141</td>
<td>Aug91, Aug92</td>
<td>24.2</td>
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<td>17.2</td>
<td>32.0</td>
<td>Pers. comm., Liu and Kingston</td>
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<td>Chiredzi, Zimbabwe, 21°01’S, 28°38’E</td>
<td>1 m sandy loam</td>
<td>Irrigated</td>
<td>NCo376, N14, ZN7, ZN6</td>
<td>Oct01</td>
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<td>NA</td>
<td>7.5</td>
<td>Zhou, 2003</td>
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<td>Chiang Mai, Thailand, 18°45’N, 98°55’E</td>
<td>1.15m sandy clay loam</td>
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<td>K84-200, U-Thong2</td>
<td>Feb95</td>
<td>11.4</td>
<td>26.4</td>
<td>34.2</td>
<td>31.3</td>
<td>Jintrawet et al., 1997</td>
</tr>
<tr>
<td>Piracicaba, Brazil, 22°53’S, 47°30’W</td>
<td>3.5m clay loam</td>
<td>Dryland, irrigated</td>
<td>NCo376, R570, SP83-2847 RB72454</td>
<td>Oct04</td>
<td>20.8</td>
<td>19.8</td>
<td>29.8</td>
<td>NA</td>
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**REFERENCES**


LE MODEL DSSAT4.5 CANEGRO: UN OUTIL D’AIDE A LA DECISION UTILE POUR LA RECHERCHE ET LA GESTION DE LA PRODUCTION DE CANNE A SUCRE

Par

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MOTS CLÉS: Modèle de Croissance, Biomasse, Masse de Saccharose, Indice Foliaire, Simulation.

Résumé

LE NOUVEAU modèle Canegro DSSATv4.5 permet aux utilisateurs de combiner les dernières avancées en modélisation de la canne à sucre avec les toutes dernières fonctionnalités de la plateforme DSSAT pour résoudre des problèmes de recherche et de production. Les objectifs de ce poster sont (1) de décrire les caractéristiques principales du modèle, (2) de montrer sa capacité à simuler la biomasse, et les rendements en canne et en sucre dans différentes parties du monde, et (3) d’exposer les applications potentielles en gestion et recherche sur la canne à sucre. Le modèle utilise des données climatiques journalières pour simuler le développement du couvert, l’interception du rayonnement, l’accumulation de biomasse et sa partition. Il simule l’effet du stress hydrique et de la verse sur la photosynthèse, la croissance et le stockage du saccharose. 18 paramètres variétaux sont utilisés pour simuler le contrôle génétique de la réponse des plantes aux

EL MODELO CANEGRO DSSAT4.5: UNA HERRAMIENTA UTIL EN LA TOMA DE DECISIONES EN INVESTIGACION Y GESTION DE LA PRODUCCION DE CANA DE AZUCAR

Por

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PALABRAS CLAVE: Modelo de Cultivo, Biomasa, Producción de Sacarosa, Índice de Área Foliar, Simulación.

Resumen

El nuevo modelo Canegro DSSATv4.5 permite a los usuarios combinar los últimos avances en modelación de caña de azúcar con la funcionalidad de DSSAT para abordar problemas en investigación y producción. Los objetivos del presente poster son (1) describir las funciones principales del modelo, (2) reportar su precisión para simular rendimientos de biomasa, caña y azúcar en diversas partes del mundo y (3) resaltar aplicaciones potenciales en gestión e investigación en caña de azúcar. El modelo utiliza datos diarios de clima para simular el desarrollo del follaje, la intercepción de la radiación, así como la acumulación y partición de biomasa. Además simula el efecto del estrés hídrico y acáme en la fotosíntesis, crecimiento y almacenamiento de azúcar. Se utilizaron 18 parámetros del cultivar para simular el control genético de la respuesta de la planta a los factores ambientales. Se comparó el índice de área foliar, biomasa aérea, cantidad de tallos y sacarosa con datos de Australia, Brasil, Sudáfrica, Tailandia y Zimbabwe. El modelo funcionó notablemente bien para estas diversas condiciones de cultivo y tipos de cultivares. En algunos casos, los índices de acumulación de biomasa decrecieron muy rápidamente en invierno, lo cual causó una subestimación de los rendimientos. Es necesario continuar la investigación en ese aspecto. Actualmente el modelo Canegro DSSATv4.5 es fácilmente accesible y, luego de cuidadosas pruebas, puede aplicarse a nivel mundial para apoyar la investigación y gestión.
N AND K FERTILISATION OF SUGARCANE RATOONS HARVESTED WITHOUT BURNING

By

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KEYWORDS: Green Cane, Sugarcane Nutrition, Potassium, Nitrogen.

Abstract
THE CURRENT production capacity of Brazilian sugarcane is mainly based in the State of São Paulo, which accounts for approximately 60\% of national production. São Paulo state has environmental regulations prohibiting the burning of sugarcane before harvesting. The residue layer left on the soil surface can interfere with fertilisation, by recycling some nutrients and also making fertiliser incorporation more difficult. In order to verify if N and K rates recommended for the burnt cane ratoon system are different from green cane, in this paper we report the response of sugarcane ratoons to different nitrogen and potassium fertiliser application rates in green cane systems. Fifteen experiments were established in several regions of São Paulo State, Brazil. All the experiments had crop residue (trash) from plant cane remaining on the soil surface since sugarcane was mechanically harvested without burning. Fertilisers were applied over the trash at the rates of: 0, 60, 120 and 180 kg/ha of N and 0, 70, 140 and 210 kg/ha of K\textsubscript{2}O. Each experiment was harvested after 12 months of growth. Our results showed significant responses to N application in 14 experiments, and significant responses to K fertilisation in 7 experiments. Nitrogen and K\textsubscript{2}O application rates that produced optimum cane yields were: N = 148 kg/ha and K\textsubscript{2}O = 125 kg/ha; however, economically profitable rates were N = 120 kg/ha and K\textsubscript{2}O = 70 kg/ha. Productivity gains did not offset costs when rates were higher than 120 kg/ha of N and 70 kg/ha of K\textsubscript{2}O. Sugarcane residues contributed mainly to sugarcane potassium nutrition.

Introduction
A great challenge facing the sugarcane industry in Brazil these days is to improve overall productivity, decrease production costs and improve sustainability. Sugarcane production systems in São Paulo State, Brazil, have experienced several modifications over time, especially due to new environmental regulations prohibiting crop burning. The sugarcane crop is now mechanically harvested without burning resulting in great amounts of residue on the soil surface. After several years of residue application, the trash layer can interfere with fertilisation, since residues make fertiliser incorporation more difficult. Our objective in this experiment was to update sugarcane fertilisation recommendations regarding N and K application in sugarcane ratoons harvested without burning. Fifteen experiments were established in the state of São Paulo, Brazil. Productivity responses were verified across differing rates of N and K application.

Material and methods
Fifteen experiments were carried out in diverse regions in São Paulo State, Brazil, including the main sugarcane production environments (named A, B, C, D and E). The production
environments are defined by soil fertility status and the ability to store water for sugarcane crop. So, it is expected that sugarcane cultivation in environment A will achieve high productivity. In environment E, productivity is expected to be very low. In São Paulo state, sugarcane is grown mainly in environments B, C and D (Prado et al., 2008).

In addition, areas with different soil potassium levels were selected (Figure 1). The experiments were installed primarily in the first and second ratoon crops, with one of the trials implemented in third ratoon. All the experiments were established following mechanical harvest without burning. Table 1 presents the description of the 15 sites.

### Table 1—Regions, soil types, environmental groups and varieties for each experiment.

<table>
<thead>
<tr>
<th>Region</th>
<th>Soil Taxonomy</th>
<th>Environmental group</th>
<th>Variety</th>
<th>Ratoon</th>
</tr>
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<tbody>
<tr>
<td>Andradina</td>
<td>Typic Hapludox</td>
<td>D</td>
<td>SP81-3250</td>
<td>1st.</td>
</tr>
<tr>
<td>Araçatuba</td>
<td>Arenic Hapludult</td>
<td>E</td>
<td>RB72454</td>
<td>2nd.</td>
</tr>
<tr>
<td>Araras</td>
<td>Rhodic Eutrudox</td>
<td>B</td>
<td>RB855453</td>
<td>2nd.</td>
</tr>
<tr>
<td>Guaira1</td>
<td>Rhodic Acrudox</td>
<td>D</td>
<td>SP80-1816</td>
<td>1st.</td>
</tr>
<tr>
<td>Guaira 2</td>
<td>Typic Hapludox</td>
<td>C</td>
<td>SP81-3250</td>
<td>2nd.</td>
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<tr>
<td>Iracemápolis</td>
<td>Rhodic Eutrudox</td>
<td>B</td>
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<td>1st.</td>
</tr>
<tr>
<td>Orindiuva</td>
<td>Arenic Hapludult</td>
<td>E</td>
<td>RB835054</td>
<td>2nd.</td>
</tr>
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<td>Piracicaba</td>
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<td>IAC89 3396</td>
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<tr>
<td>Planalto</td>
<td>Xantic Hapludox</td>
<td>E</td>
<td>RB72454</td>
<td>3rd.</td>
</tr>
<tr>
<td>Pradôpolis</td>
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<td>D</td>
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<td>RB867515</td>
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<td>Ribeirão Preto</td>
<td>Typic Hapludox</td>
<td>C</td>
<td>RB867515</td>
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</tr>
<tr>
<td>Santa Rita</td>
<td>Rhodic Eutrudox</td>
<td>B</td>
<td>RB72454</td>
<td>1st.</td>
</tr>
<tr>
<td>S. Joaquim Barra</td>
<td>Typic Hapludox</td>
<td>C</td>
<td>SP87-367</td>
<td>1st.</td>
</tr>
<tr>
<td>Sertãozinho</td>
<td>Typic Hapludox</td>
<td>B</td>
<td>RB855453</td>
<td>1st.</td>
</tr>
</tbody>
</table>

Fig. 1—Potassium (mmol c/dm³) in soil samples for each experiment.
The experiments were planted in a factorial design with 16 treatments placed in randomised blocks with four replications. Plots consisted of 5 rows of sugarcane 10 metres long, with between-row spacing of 1.4 and 1.5 m. N and K fertility treatments were:

- Nitrogen – 4 rates (0, 60, 120 and 180 kg/ha of N);
- Potassium – 4 rates (0, 70, 140 and 210 kg/ha of K₂O).

The fertiliser sources were ammonium nitrate and potassium chloride. Each experiment was harvested following 12 months of growth. The plots were weighed with a dynamometer to determine cane yield (t/ha).

Statistical analyses of variance for a factorial design was performed using SAS, and Tukey means separations were calculated with P = 0.05. Productivity responses were also estimated by SAS.

Results and discussion

Cane yield results for each fertilisation treatment from all 15 sites are presented in Table 2. Results differed among locations; however, this was expected since different production environments, sugarcane varieties and crop longevity were studied. Higher cane yields were measured in experiments carried out in environments classified as B or C, as well as in the younger ratoons.

Based on the results, it can be established that soil classification and water storage capacity are very important to predict cane productivity. Chalita (1991), determined that the soil level of potassium critical for cane growth in the State of São Paulo, Brazil, was 1.2 mmol c/dm³ for first ratoon cane. Our experiments show that lower cane productivities were obtained in soils when potassium levels were < 1 mmol c/dm³ of K. Average yields at each location can be observed in Figure 2. Higher productivity locations were: Araras, Iracemápolis, Guaira 2, Piracicaba, Ribeirão Preto, Sertãozinho and S. Rita.

<table>
<thead>
<tr>
<th>Rates (kg/ha)</th>
<th>Andradina</th>
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<th>Araras</th>
<th>Guaira1</th>
<th>Guaira 2</th>
<th>Iracema polis</th>
<th>Orindiuva</th>
<th>Planalto</th>
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<td>N 0 K 0</td>
<td>65.62</td>
<td>68.25</td>
<td>124.01</td>
<td>54.20</td>
<td>94.22</td>
<td>83.33</td>
<td>65.39</td>
<td>41.01</td>
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<td>94.64</td>
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<td>132.45</td>
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<td>88.21</td>
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** significant at p = 0.01; msd = minimum significant difference p=0.05
Table 2 (Cont.)—Sugarcane yield (t/ha) for each treatment and experiment.

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<th>Rates (kg/ha)</th>
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<th>S.Joaquim Barra</th>
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<td>2.22**</td>
<td>1.71*</td>
<td>1.69**</td>
</tr>
<tr>
<td>8.73</td>
<td>8.36</td>
<td>10.90</td>
</tr>
<tr>
<td>5.67</td>
<td>6.58</td>
<td>8.90</td>
</tr>
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</table>

** significant at p = 0.01; msd = minimum significant difference p=0.05

Fig. 2—Average cane yield at each location.
Statistical analyses of cane yield responses indicated that nitrogen significantly increased cane yield in 14 experiments and potassium increased cane yield in 7 trials. Thornburn et al. (2002) estimated that N application rates for sugarcane harvested without burning should be 60 kg per ha higher than burnt cane.

Higher N doses are required following green sugarcane harvest because the water storage capacity is higher and, consequently, the biomass accumulation can be increased. Also, there is a need to compensate for soil nitrogen immobilisation in the crop residue. These were the main reasons for cane yield responses to nitrogen in 14 of the 15 locations.

Sugarcane production systems with crop burning are considered highly responsive to potassium fertilisation in both the plant cane and ratoon crops (Rossetto et al. 2004). However, in green cane systems, the crop residues can add substantial amounts of K.

Oliveira et al. (2002) estimated that remaining trash can recycle approximately 65 kg/ha of K2O. The potassium present in green cane residues can be rapidly transferred to the soil and supplied for the cane crop which means that sugarcane response to potassium fertilisers is reduced.

In fact, significant response to K fertilisation occurred only in 7 of the 15 locations even in soils with low potassium levels at Araçatuba, Guaira2, Planalto, Promissão, S. Rita and S. Joaquim da Barra.

Nitrogen and potassium rates for optimum cane yields were estimated for the 15 locations as N = 148 kg/ha and K2O = 125 kg/ha. Nevertheless, due to the high fertiliser costs, the economical rate of application was 120 kg/ha of N and 70 kg/ha of K2O.

When higher rates were applied, the cane yield gain did not exceed 3 t/ha and therefore did not offset the increased fertiliser costs.

Sugarcane ratoon yield response curves to N and K fertilisation rates (average for 15 field experiments) can be observed in Figures 3 and 4.

![Fig. 3—Sugarcane ratoon yield response to nitrogen fertilisation rates. (Average for 15 field experiments).](image-url)
Conclusions

N fertilisation significantly increased cane yield in green cane systems in 14 of 15 locations whereas K fertilisation increased cane yield at only 7 locations.

Nitrogen and potassium fertilisation rates for optimum cane yields were: N = 148 kg/ha K$_2$O = 125 kg/ha. However, the most profitable rates were: N = 120 kg/ha and K$_2$O = 70 kg/ha.

REFERENCES


FERTILISATION AZOTEE ET POTASSIQUE SUR DES REPOUSSES DE CANNE A SUCRE RECOLTEES SANS BRULAGE

Par

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\(^2\)APTA – Centro de Solos/IAC
\(^3\)Unesp – Jaboticabal

MOTS CLÉS: Canne en Vert, Nutrition de la Canne à Sucre, Potassium, Azote.

Résumé

DE NOS JOURS, la capacité de production de canne à sucre du Brésil est principalement concentrée dans l’Etat de São Paulo avec environ 60% de la production nationale. L’Etat de São Paulo obéit à des règles environnementales interdisant le brûlage de la canne avant la récolte. Les résidus laissés sur le sol peuvent interférer avec la fertilisation en recyclant des éléments nutritifs et aussi en rendant plus difficile l’incorporation de la fertilisation. Afin de vérifier si les taux de N et K recommandés pour les repousses d’une canne coupée après brûlage sont différents pour la canne coupée en vert, nous présentons dans ce papier la réponse de la canne en repousse à divers niveaux d’engrais azoté et potassique épandus après une coupe en vert. Quinze essais ont été implantés dans diverses régions de l’Etat de São Paulo, Brésil. Tous les essais avaient des résidus de récolte (paillis) à la surface du sol puisque la canne en vierge avait été récoltée mécaniquement sans brûlage. Les engrais avaient été appliqués sur le paillis aux taux de: 0, 60, 120 et 180 kg/ha pour N et 0, 70, 140 et 210 kg/ha pour K\(_2\)O. Chaque essai a été récolté à l’âge de 12 mois. Nos résultats ont montré des réponses significatives à l’application de N dans 14 essais et dans 7 essais pour K. Les taux de N et K\(_2\)O qui ont produit les rendements canne optimaumes ont été: 148 kg/ha pour N et 125 kg/ha pour K\(_2\)O, cependant économiquement la dose rentable est de 120 kg/ha pour N et 70 kg/ha pour K\(_2\)O. Les gains de productivité n’ont pas compensé les coûts quand les taux d’application étaient plus élevés que 120 kg/ha en N et 70 kg/ha en K\(_2\)O. Les résidus de canne à sucre contribuent principalement à la nutrition potassique de la canne à sucre.
FERTILIZACION CON N Y K DE CANA DE AZUCAR EN SOCAS COSECHADAS SIN QUEMAR

Por

R. ROSSETTO¹, F.L.F. DIAS¹, M.G.A. LANDELL¹, H. CANTARELLA², S. TAVARES¹, A.C. VITTI¹ and D. PERECIN³

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³Unesp – Jaboticabal

PALABRAS CLAVE: Cosecha en Verde, Nutrición de Cana de Azúcar, Potasio, Nitrógeno.

Resumen

La capacidad de producción actual de la caña de azúcar en Brasil tiene base principalmente en el estado de São Paulo, pues representa el 60% de la producción nacional. El estado de São Paulo posee regulaciones ambientales que prohíben la quema de la caña de azúcar antes de cosecharla. La capa de residuos que queda sobre la superficie del suelo puede interferir con la fertilización, a través del reciclaje de algunos nutrientes, pero también dificultando la incorporación de fertilizante. Con el fin de verificar si las dosis de N y K recomendadas para la cosecha de caña quemada difieren de aquellas para cosecha de caña en verde, en el presente trabajo se reporta la respuesta del cultivo de la caña de azúcar en socas, a la aplicación de diferentes dosis de fertilizantes nitrogenados y potásicos en cosecha en verde. Se establecieron 15 experimentos en diversas regiones del estado de São Paulo, Brasil. Todos los experimentos tenían residuos de la cosecha (trash) sobre la superficie del suelo, pues la caña se cosecho mecánicamente, sin quemar. Los fertilizantes se aplicaron sobre el trash, en dosis de 0, 60, 120 y 180 kg/ha de N y 0, 70, 140 y 210 kg/ha de K₂O. Cada experimento se cosecho después a los 12 meses. Los resultados muestran respuestas significativas a la aplicación de N en 14 experimentos, así como respuestas significativas a la aplicación de K en siete experimentos. Las dosis de N y K₂O que produjeron rendimientos óptimos fueron: N = 148 kg/ha y K₂O = 125 kg/ha; sin embargo, las dosis óptimas económicas fueron: N = 120 kg/ha y K₂O = 70 kg/ha. Las ganancias en productividad no compensaron los costos cuando las dosis fueron mayores a 120 kg/ha de N and 70 kg/ha of K₂O. Los residuos contribuyeron, principalmente con los requerimientos de potasio de la caña de azúcar.
THE USE OF A HUMIC ACID-BASED SOIL CONDITIONER IN SUGARCANE CROP

By

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KEYWORDS: Saccharum spp, Fertilisation, Productivity, Humic acid.

Abstract

Efforts have been made to find ways to increase the productivity of sugarcane crops by using less mineral fertilisers, leading to a cost reduction and sustainability. Based on these principles, organic-mineral products have been used to promote physical, chemical and biological alterations in the soil system. The use of a commercial humic acid-based soil conditioner product was evaluated, in order to measure its influence on sugarcane production and to check its interaction with the mineral fertilisation. The experiment was carried out on Santa Candida sugar mill, located in Bocaina, São Paulo state, using the sugarcane varieties RB 867515 (plant cane), and PO88-62 (ratoon). The experiment was laid out in a split-plot design, using 0, 800, 1600 and 2400 kg/ha of the mineral fertiliser 2.5–10–10 (main plot treatments) with 0 and 350 litres/ha of the commercial product (sub-plot treatments) at sugarcane planting, and 0, 800, 1600 and 2400 kg/ha of the mineral fertiliser 10–00–10 (main plots) with 0, 300 and 600 litres/ha of the commercial product (sub-plots), at first ratoon. Results showed that the use of the commercial product causes a significant increase in the crop production, both in plant cane and first ratoon, equivalent to the use of 1200 and 1100 kg/ha (interpolated) of the mineral fertiliser.

Introduction

Organic matter providing enormous benefits to agricultural production is ancient knowledge, but yet little is known about it. Use of organic matter improves soil physical, chemical and biological properties, and has technical advantages.

However, due to high cost and / or large volumes required, the application of organic matter as fertiliser in fields is limited to a small group of growers.

Composition of soil organic matter is still unknown by the great diversity and variability of compounds and origins, but is generally called ‘humus’ due to the large presence of humic acid, which appears to be the ‘active principle’.

Many attempts have been made to increase sugarcane productivity. One of them is to use mineral fertilisers more efficiently, and thus reduce costs and sustain production of the sugar-alcohol sector.

Under this principle, organic minerals with a humic-acid base were selected with the aim to improve the level of soil organic matter, and soil physical, chemical and biological properties.

This work was to determine the effect of an organic soil conditioner, organic mineral humic acid, in plant and ratoon cane. Furthermore, its interaction with mineral fertiliser was also investigated.
Materials and methods

Two trials were conducted at Santa Cândida Mill, City of Bocaina – SP. The first trial was plant cane of variety RB 867515 located in Farm Bateia, with neosoil quartzenic sandy soil found in the production environment D1 (Prado, 2005). After opening the furrows, the application of the organic mineral product was done at the same time as the application of mineral fertiliser. The second trial was ratoon cane of variety PO88-62 located in Farm Santa Inês, with neosoil quartzenic sandy soil found in the production environment D2 (Prado, 2005). The application of organic mineral was performed during the mechanical cultivation of the ratoon.

Experimental design for both trials was randomised blocks in split plots with 4 replications. The main treatment was fertiliser rates. In the plant cane trial, there were two rates of the organic mineral (0 and 350 L/ha) in combination with 0, 800, 1600 and 2400 kg/ha of liquid fertiliser 2.5–10–10. However, in the ratoon cane trial, there were three rates of the organic mineral product (0, 300 and 600 L/ha) in combination with 0, 800, 1600 and 2400 kg/ha of liquid fertiliser 10–0–10. Each plot comprised four rows, 50 metres in length. Samples were taken from the middle 30 metres.

The Agrolmin® organic mineral product used in the experiment was obtained by extraction from a natural peat mine with the following properties: pH = 5.67, total organic matter (humic substances) = 89.72%, total N 5% (patronised from the natural product complemented with mineral N).

At harvesting, cane was cut, weighed and evaluated. Analysis of variance was performed by SAS statistical program, the test medium analysed by the Tukey test at 5% significance.

Results and discussion

There was a significant difference in cane yield related to the rates 1600 and 2400 kg/ha of mineral fertiliser when compared to the control. However, there was no significant difference between the rates of 800, 1600 and 2400 kg/ha. It was also found that the use of 350 L/ha significantly increased the cane yield to 177.78 t/ha, compared to the control, 130.02 t/ha (Table 1).

<table>
<thead>
<tr>
<th>Fertiliser</th>
<th>Rates</th>
<th>Productivity (t/ha)</th>
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</thead>
<tbody>
<tr>
<td>Mineral fertiliser</td>
<td>1600</td>
<td>129.17 a</td>
</tr>
<tr>
<td>(kg/ha)</td>
<td>2400</td>
<td>128.35 a</td>
</tr>
<tr>
<td></td>
<td>800</td>
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<td></td>
<td>0</td>
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<tr>
<td>(L/ha)</td>
<td>0</td>
<td>130.02 b</td>
</tr>
</tbody>
</table>

Means followed by the same letter are not different by Tukey test at 5% probability for all treatments.

In ratoon cane, there was a significant response in cane yield (Table 2) using the Agrolmin® compared to the control, but no significant difference between rates of 300 L/ha and 600 L/ha.

<table>
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<tr>
<th>Fertiliser</th>
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<td></td>
<td>800</td>
<td>116.71 ab</td>
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<td>100.97 b</td>
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<tr>
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<td>600</td>
<td>125.13 a</td>
</tr>
<tr>
<td>(L/ha)</td>
<td>300</td>
<td>122.19 a</td>
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<td>104.81 b</td>
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</table>

Means followed by the same letter are not different by Tukey test at 5% probability.
With regard to mineral fertiliser, there was a significant difference between the rates of fertiliser and control, but no significant difference between the rates of fertiliser at 800, 1600 and 2400 kg/ha. No significant interaction between rates of mineral fertilisers and rates of Agrolmin® were found.

It was also observed during the conduct of experiments that both plant and ratoon cane treated with humic acid showed fewer symptoms of a drought-like root system, thinner stalks and shorter internodes than the plots without this input.

Cane yield was increased by number of tillers and larger diameter of the cane stalks. These symptoms are related to improved plant nutrition by greater absorption of nutrients.

Increased availability of nutrients, particularly nitrogen, was directly related to the increase in the diameter of stem and tillering of culture (Van Dillewijn, 1952; Humbert, 1968; Alexander, 1973; Clements, 1980; Rodrigues et al., 1983; Beauclair, 1984).

This increased availability of nitrogen is related to an increase in content and, consequently, the decomposition and mineralisation of organic matter, as suggested by Beauclair (1984), provided by using humic acid.

Although these results showed that the use of humic acid resulted in a consistent increase in cane yield, it does need a greater number of studies and analysis of the issue to better characterise the causes and effects.

Conclusions

For the cane plant, the use of a commercial product of humic acid of 350 L/ha resulted in a significant increase in cane yield, and the rate equivalent to the use of 800 kg/ha of mineral fertiliser.

In ratoon cane, the rates of 300 and 600 L/ha of humic acid resulted in a significant increase of cane yield equal to 1200 kg/ha of mineral fertiliser.

Use of this soil conditioner may be feasible to increase production combined with a reduction of mineral fertiliser.

REFERENCES


L’UTILISATION D’UN ACTIVATEUR DE SOL HUMIQUE
ACIDE EN CULTURE DE CANNE À SUCRE

Par

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KEYWORDS: Saccharum spp, Fertilisation,
Productivité, Acide Humique.

Résumé

Des efforts ont été réalisés pour trouver des solutions permettant d’augmenter la productivité des cultures de canne à sucre, diminuer les coûts et augmenter la durabilité. Basé sur ces principes, des engrais organo-minéraux ont été utilisés pour améliorer les propriétés physiques, chimiques et biologiques du sol. Un produit commercial activateur de sol humique acide fut évalué en mesurant son influence sur la production de la canne à sucre et son interaction avec la fertilisation minérale. L’expérimentation fut réalisée sur le complexe de Santa Candida sugar mill, situé en Bocaina, dans l’état de São Paulo, avec les variétés RB 867515 en canne plantée et PO 88-62 en repousse. Le dispositif en split plot comportait les doses d’engrais minéraux en parcelles principales et les doses de produit commercial en sous parcelles. A la plantation, des doses (0, 800, 1600 et 2400 kg/ha) d’engrais minéraux (2.5–10–10) et des doses de 0 et 350 l/ha de produit commercial furent appliquées. En repousse, des doses (0, 800, 1600 et 2400 kg/ha) d’engrais minéraux (10–00–10) et des doses de 0, 300 et 600 l/ha de produit commercial furent appliquées. Les résultats montrèrent que l’application de produit commercial augmente significativement la production à la fois en canne plantée et en repousse, ce qui équivaut par interpolation à une utilisation de 1200 et 1100 kg d’engrais minéral.
Utilización de un acondicionador de suelo a base de ácido húmico en el cultivo de la caña de azúcar

Por
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Palabras clave: Saccharum spp., Fertilización, Productividad, Ácido Húmico.

Resumen
Se han realizado esfuerzos para incrementar la productividad del cultivo de la caña de azúcar utilizando menos fertilizantes minerales, con el objeto de reducir costos y lograr sostenibilidad. Con base en estos principios, se han utilizado productos orgánico-minerales para promover alteraciones físicas, químicas y biológicas en el sistema suelo. Se evaluó la utilización de un acondicionador de suelo a base de ácido húmico, con el fin de medir su influencia en la producción de caña de azúcar y su interacción con la fertilización mineral. El experimento se llevó a cabo en el ingenio Santa Candida, ubicado en Bocaina, estado de San Pablo, con las variedades RB86-7515 (plantía) y PO88-62 (soca). Se utilizó un diseño experimental de parcelas divididas, aplicando 0, 800, 1600 y 2400 kg/ha del fertilizante mineral 2.5–10–10 (parcela grande) con 0 y 350 litros/ha del producto comercial (parcela pequeña) en plantía, y 0, 800, 1600 y 2400 kg/ha del fertilizante mineral 10–00–10 (parcela grande) con 300 y 600 litros/ha del producto comercial (parcela pequeña) en soca. Los resultados muestran que el uso del producto comercial provoca un incremento en la producción del cultivo, tanto en plantía como en soca, equivalente al uso de 1200 y 1100 kg/ha (interpolando) del fertilizante mineral.
EFFECTS OF SUBSOILING ON ALFISOL SOIL
PHYSICAL PROPERTIES IN COLOMBIA

By

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KEYWORDS: Subsoiler, Tillage,
Physical Properties, Cane Sugar, Soil.

Abstract
A STUDY was conducted to evaluate the effects of subsoiling on the soil physical properties in the Providencia Sugar Mill S.A. in Colombia. A Steiger tractor of 225 HP and parabolic subsoiler were used with different velocities (3.0 to 4.2 km/h) and spacing between shanks (1.1 to 1.4 m). The soil studied was an Alfisol of the Argelia series with clay texture. The soil properties, namely available water capacity, breaking area, moisture content and lower limit of plasticity, were measured to a depth of 80 cm. Average soil moisture content at the time of the test (13.0%) was below the lower plastic limits (18.10%) in the 0–30 cm layer. When the spacing between shanks was decreased and velocity increased, breaking area increased from 1.4 m² to 1.6 m² and available water content was increased from 16.64% to 20.13%. In conclusion, the subsoiling tillage increased the breaking area and available water content when spacing between shanks was 1.1 m and velocity was 4.2 km/h and decreased soil compaction in an Alfisol soil.

Introduction
Soil compaction is generated by machinery traffic during harvest and agricultural operations. This compaction is related to the moisture content in the soil. Compaction modifies the soil physical properties such as bulk density, penetration resistance, infiltration, available water capacity and can create problems of crop development and decreased production.

To reduce soil compaction, subsoiling is used during soil preparation and also in ratoons. The soil preparation is carried out before planting by two passes to increase the broken area and by one pass between the rows in ratoons.

Factors influencing the soil breaking of the subsoiler are: moisture content, velocity of the tillage, depth and spacing between shanks, design of the implement. This study evaluated the subsoiler use in tillage of sugarcane crops and its effect on soil physical properties such as available water capacity and breaking area.

Material and methods
The trial was carried out in Topacio farm near to Providencia sugar mill in Colombia. The soil is Argelia (Alfisol) with clay texture. A 225 HP tractor was used with parabolic shaped subsoiler. Distances between shanks were: S1=1.1 m, S2=1.3 m and S3=1.4 m, working at a depth of 0.60 m. The working velocity varied between V1=3.20, V2=3.7 and V3=4.15 km/h. The trial plots had an average area of 2 ha.

A hole with dimensions 3x0.80 m and depth 0.80 m was built. A cone penetrometer was used to measure the compaction every 0.20 m and the effect on the soil in the breaking area was determined. The moisture content was measured with pressure plates and rings by the Casagrande method (Gonzales, 1979). The soil samples were evaluated at 0–30 and 30–60 m layers.
The parameters assessed were: penetration resistance, moisture content, available water capacity, plastic limits and the area of breaking by the subsoiler. A 5% probability level was used to test the significance of differences between treatments. The soil samples were evaluated in the soil laboratory of the National University of Colombia.

Results and discussion

Moisture content

Table 1 shows that, in the 0–60 cm layer in the different trials, the moisture content (MC) was lower than the lower plastic limit (LPL). The subsoiling was in the friable range at the 0–60 cm layer, according to the study by Asae (1971), Bukhari (1990), Girón (1992), Gavande (1987) and Chancellor (1971).

<table>
<thead>
<tr>
<th>TEST</th>
<th>Layer 0–30</th>
<th>Layer 30–60</th>
</tr>
</thead>
<tbody>
<tr>
<td>L.P.L.</td>
<td>18.10</td>
<td>31.78</td>
</tr>
<tr>
<td>V1–S1</td>
<td>13.93</td>
<td>11.12</td>
</tr>
<tr>
<td>V2–S1</td>
<td>15.88</td>
<td>11.70</td>
</tr>
<tr>
<td>V3–S1</td>
<td>12.44</td>
<td>11.20</td>
</tr>
<tr>
<td>V1–S2</td>
<td>13.95</td>
<td>10.96</td>
</tr>
<tr>
<td>V2–S2</td>
<td>10.52</td>
<td>10.66</td>
</tr>
<tr>
<td>V3–S2</td>
<td>11.02</td>
<td>11.32</td>
</tr>
<tr>
<td>V1–S3</td>
<td>13.61</td>
<td>14.53</td>
</tr>
<tr>
<td>V2–S3</td>
<td>13.84</td>
<td>14.18</td>
</tr>
<tr>
<td>V3–S3</td>
<td>11.74</td>
<td>11.09</td>
</tr>
</tbody>
</table>

Penetration resistance

The values decreased in general with respect to initial values (Table 2). These values were 12.41 kg/cm² in the 0–20 cm layer and decreased to 0.27 kg/cm² in 0–20 cm layer in V1-S1. This shows that subsoiling is beneficial for breaking the soil and agrees with Adeoye (1982), Asae (1971) and Chancellor (1971).

<table>
<thead>
<tr>
<th>Test</th>
<th>Layer–cm 0–20</th>
<th>Layer–cm 20–40</th>
<th>Layer–cm 40–60</th>
<th>Layer–cm 60–80</th>
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<td>Initial</td>
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<td>3.20</td>
<td>0.76</td>
<td>0.76</td>
</tr>
<tr>
<td>V1–S1</td>
<td>0.27</td>
<td>0.59</td>
<td>0.28</td>
<td>0.69</td>
</tr>
<tr>
<td>V2–S1</td>
<td>0.41</td>
<td>0.70</td>
<td>0.94</td>
<td>0.70</td>
</tr>
<tr>
<td>V3–S1</td>
<td>1.70</td>
<td>0.97</td>
<td>1.65</td>
<td>0.67</td>
</tr>
<tr>
<td>V1–S2</td>
<td>0.76</td>
<td>1.23</td>
<td>1.61</td>
<td>1.15</td>
</tr>
<tr>
<td>V2–S2</td>
<td>0.47</td>
<td>1.24</td>
<td>1.73</td>
<td>1.18</td>
</tr>
<tr>
<td>V3–S2</td>
<td>1.26</td>
<td>1.46</td>
<td>2.09</td>
<td>1.18</td>
</tr>
<tr>
<td>V1–S3</td>
<td>1.56</td>
<td>1.07</td>
<td>0.79</td>
<td>1.44</td>
</tr>
<tr>
<td>V2–S3</td>
<td>1.39</td>
<td>0.70</td>
<td>1.04</td>
<td>1.44</td>
</tr>
<tr>
<td>V3–S3</td>
<td>1.85</td>
<td>0.81</td>
<td>1.37</td>
<td>1.44</td>
</tr>
</tbody>
</table>

Breaking area

Table 3 shows values of the breaking area in different trials. The breaking area decreased when distance between shanks of 1.56 m² in V3-S1 to 1.17 m² in V3-S3 increased. With increased velocity, the breaking area increased from 1.47 m² in V1-S1 trial to 1.56 m² in V3-S1. The breaking
area increased with a lower spacing between shanks and higher velocity. Similar data were found by Hendrick and Gill (1973), Ide et al. (1987) and Rodriguez (2008).

<table>
<thead>
<tr>
<th>Test</th>
<th>m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1–S1</td>
<td>1.473</td>
</tr>
<tr>
<td>V2–S1</td>
<td>1.505</td>
</tr>
<tr>
<td>V3–S1</td>
<td>1.561</td>
</tr>
<tr>
<td>V1–S2</td>
<td>0.903</td>
</tr>
<tr>
<td>V2–S2</td>
<td>1.050</td>
</tr>
<tr>
<td>V3–S2</td>
<td>1.185</td>
</tr>
<tr>
<td>V1–S3</td>
<td>0.876</td>
</tr>
<tr>
<td>V2–S3</td>
<td>0.954</td>
</tr>
<tr>
<td>V3–S3</td>
<td>1.173</td>
</tr>
</tbody>
</table>

**Available water capacity**

The initial value was 11.11% in the 0–30 cm layer (Table 4). The available water capacity (AWC) increased when the separation between shanks of the subsoiler decreased and with an increase in the velocity. This value ranged from 16.64% in V1-S1 to 20.13% in V3-S1 trial, in the 0–30 cm layer. Studies by Asae (1971) and Girón found increases in AWC.

<table>
<thead>
<tr>
<th>Test</th>
<th>Layer (cm)</th>
<th>0–30</th>
<th>30–60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>11.11</td>
<td>12.55</td>
<td></td>
</tr>
<tr>
<td>V1-S1</td>
<td>16.64</td>
<td>6.37</td>
<td></td>
</tr>
<tr>
<td>V2-S1</td>
<td>18.72</td>
<td>8.62</td>
<td></td>
</tr>
<tr>
<td>V3-S1</td>
<td>20.13</td>
<td>11.18</td>
<td></td>
</tr>
<tr>
<td>V1-S2</td>
<td>9.18</td>
<td>10.03</td>
<td></td>
</tr>
<tr>
<td>V2-S2</td>
<td>9.57</td>
<td>11.60</td>
<td></td>
</tr>
<tr>
<td>V3-S2</td>
<td>15.03</td>
<td>13.46</td>
<td></td>
</tr>
<tr>
<td>V1-S3</td>
<td>7.62</td>
<td>10.73</td>
<td></td>
</tr>
<tr>
<td>V2-S3</td>
<td>9.40</td>
<td>11.52</td>
<td></td>
</tr>
<tr>
<td>V3-S3</td>
<td>13.08</td>
<td>12.54</td>
<td></td>
</tr>
</tbody>
</table>

**Conclusions**

The subsoiling in soil preparation reduces the compaction of the soils.
High velocity tillage and lower spacing between shanks increases the breaking area and available water capacity.

The moisture content in soil should be lower than the lower plastic limit for good performance of the subsoiler.

**REFERENCES**


EFFETS DU SOUS-SOLAGE SUR LES PROPRIETES PHYSIQUES D’UN ALFISOL EN COLOMBIE

Par

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Résumé

AFIN D’ÉVALUER les effets du sous-solage sur les propriétés physiques du sol, une étude a été réalisée sur le site de la Providencia Sugar Mill S.A. en Colombia. Un sous-soleur parabolique tracté par un tracteur Steiger de 225 HP a été utilisé à différentes vitesses (3.0 et 4.2 km/h) et espacements (1.1 et 1.4 m) entre étançons. Le sol étudié était un Alfisol à texture argileuse de la série Argélia. Les propriétés du sol, c’est-à-dire la capacité en eau disponible, la surface de cassure, la teneur en eau et la limite inférieure de plasticité ont été mesurées jusqu’à une profondeur de 80 cm. La teneur en eau moyenne au moment du test (13%) était inférieure à la limite inférieure de plasticité (18%) dans la couche 0–30cm. La diminution de l’espacement et l’augmentation de la vitesse ont entraîné des augmentations de la surface de cassure de 1.4 m² à 1.6 m² et de la teneur en eau disponible de 16.4% à 20.13%. En conclusion, le sous-solage en diminuant l’écartement et en augmentant la vitesse, augmente la surface de cassure, la teneur en eau disponible du sol et diminue la compaction d’un Alfisol.
EFECTOS DEL SUBSOLADO SOBRE LAS PROPIEDADES FÍSICAS DE UN SUELO ALFISOL EN COLOMBIA

Por

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PALABRAS CLAVE: Subsolador, Labranza, Propiedades Físicas, Azúcar de Caña, Suelo.

Resumen

SE REALIZÓ un estudio para evaluar los efectos del subsolado sobre las propiedades físicas del suelo en el ingenio Providencia S.A. en Colombia. Se utilizó un tractor Steiger de 225 HP y un subsolador parabólico, a distintas velocidades (3.0–4.2 km/h) y diversos espacios entre brazos (1.1 a 1.4 m). El suelo bajo estudio fue un Alfisol de la serie Argelia con textura arcillosa. Las propiedades del suelo, tales como capacidad de retención de agua, área de ruptura, contenido de humedad y límite mínimo de plasticidad se midieron a una profundidad de 80 cm. El contenido de humedad promedio en el suelo al momento de la evaluación (13.0%) estaba debajo de los límites mínimos de plasticidad (18.10%) en la capa de 0–30 cm. Cuando se redujo el espacio entre los brazos del subsolador y se aumentó la velocidad, se incrementó el área de ruptura de 1.4 m² a 1.6 m² y el contenido de agua disponible se incrementó de 16.64% a 20.13%. En conclusión, el subsolado incrementó el área de ruptura y el contenido de agua cuando se dejó un espacio entre los brazos del implemento de 1.1 m y se trabajó a una velocidad de 4.2 km/h, y se redujo la compactación de un suelo Alfisol.
A NEW FORMULATED SILICON FERTILISER
FOR BETTER SUGARCANE PRODUCTION

By

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KEYWORDS: Silicon Fertiliser, Boiler Ash, Furnace Slag, Humic Substance, Sugarcane Productivity.

Abstract

SILICON (Si) is an important beneficial element for sugarcane and is absorbed by sugarcane, more than any other mineral nutrient. Si is known to promote sugarcane yield, enhance resistance to biotic and abiotic stresses, improve leaf and stalk erectness, and increase P availability. A new Si fertiliser namely SiPlusHS was formulated from sugar mill boiler ash, furnace slag, rock phosphate, zeolite, oxalic acid and humic substance. It formed granules of 3–5 mm in diameter and contained 8–10% soluble Si, 10–12% soluble phosphate and 3–5% humic substance. The effectiveness of this fertiliser was tested under field conditions on irrigated and non-irrigated sugarcane areas, covering areas of 1 and 2 ha, respectively. The fertiliser was applied at the rate of 0, 250 and 500 kg/ha. Results showed that application of 250 kg/ha SiPlusHS could increase cane yield from 2 to 52% and sugar yield by as much as 15–58%. There were no significant differences between applications of 250 kg/ha and 500 kg/ha SiPlusHS. In some areas, SiPlusHS could significantly decrease stem borer attacks. Recently, this new silicon fertiliser has been tested on about 1000 ha in various regions in Indonesia.

Introduction

Sugarcane is an important cash crop in Indonesia and is grown over about 440 000 hectares to produce 2.65 million tonnes of sugar. The average sugar productivity in Indonesia is about 6.17 t/ha, and is the lowest among the sugarcane growing countries of the world. The average of sugar productivity is much lower than its potential yield as, in some areas, sugar productivity could reach 11.0 t/ha (Toharisman, 2009a). Unbalanced and inappropriate fertiliser use seems to be one of the factors responsible for low sugar productivity in Indonesia. Sugarcane fertilisation is still focussed on the use of nitrogen (N), phosphorus (P), and potassium (K).

Sugarcane is capable of rapidly depleting soil nutrients, particularly Si. The aerial parts of an adequately fertilised 12 months old sugarcane crop have been reported to absorb 500–700 kg/ha of Si, compared with 100–300 kg/ha of N, 40–80 kg/ha of P, and 100–300 kg/ha of K (Anderson, 1991). It is thus clear that for the long term and sustainable use of sugarcane lands, the removal of such large quantities of Si has to be balanced by adequate inputs of Si in the form of silicon fertilisers. The removal of Si could be even more important under intensive sugarcane cultivated areas in Indonesia. Mulyadi et al. (2005) reported that the main sugarcane areas in Java are deficient in Si. Matichenkov and Calvert (2002) reported that Si deficiency in sugarcane would not only cause a reduction in sugar yield but would also reduce disease and pest resistance and reduce the tolerance to biotic and abiotic stresses.

Boiler ash and furnace slag can be a source of Si to sugarcane soils in Indonesia but, in view of its low Si availability, a high rate of 1–3 t/ha would be required. In this context, the Indonesian Sugar Research Institute developed a new Si fertiliser namely SiPlusHS, using boiler ash and...
furnace slag supplemented with rock phosphate and humic substances. The object of this study was to evaluate the effects of SiPlusHS on sugarcane yields in different climatic zones in Indonesia.

Materials and methods

Silicate fertiliser formulation

SiPlusHS was prepared by mixing boiler ash (20%), furnace slag (15%), zeolite (10%), rock phosphate (52%), humic substances (2%) and oxalic acid (1%). The addition of oxalic acid enhances the solubility of Si. The mixture was left overnight and was granulated to produce granules of 3–5 mm in diameter. The granulated formulation contained 22–25% of SiO₂, 14–17% of P₂O₅ and 2% of humic substance.

Fertiliser application

Field experiments were conducted to evaluate the effect of SiPlusHS in the rainfed upland areas at Bungamayang Sugar Factory (SF), Lampung, and Tersana Baru SF, West Java as well as in irrigated areas at Tjukir SF, East Java. At Bungamayang SF, SiPlusHS was applied at three rates (1, 250 and 500 kg/ha) in combination with urea, TSP, KCl and dolomite (Table 1). Each treatment was replicated three times in a randomised complete block design. Each plot consisted of 10 cane rows, 50 m long and spaced at 1.3 m.

At Tersana Baru and Tjukir SF, silicate fertiliser was applied at two rates (0 and 250 kg/ha) and each plot size was 2 ha. At planting, all the Si, 30% of urea, and 100% of TSP were applied in the furrows and the remaining 70% of urea and 100% of MOP were applied 2 months after sowing of cane setts. Sugarcane variety PS 864 was planted at Bungamayang SF, whereas varieties PS 851 and PA 190 were planted at Tersana Baru SF and Tjukir SF, respectively. The growth, yield and quality parameters were measured at appropriate stages of growth of sugarcane using standard procedures.

Table 1—Rates of fertilisers applied at Bungamayang SF.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Urea (kg/ha)</th>
<th>TSP (kg/ha)</th>
<th>KCl (kg/ha)</th>
<th>Dolomite (kg/ha)</th>
<th>SiPlusHS (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>300</td>
<td>350</td>
<td>300</td>
<td>2500</td>
<td>250</td>
</tr>
<tr>
<td>II</td>
<td>300</td>
<td>350</td>
<td>300</td>
<td>2500</td>
<td>500</td>
</tr>
<tr>
<td>III</td>
<td>300</td>
<td>250</td>
<td>300</td>
<td>2500</td>
<td>250</td>
</tr>
<tr>
<td>Control</td>
<td>300</td>
<td>350</td>
<td>300</td>
<td>2500</td>
<td>0</td>
</tr>
</tbody>
</table>

Results and discussions

As shown in Table 2, the application of SiPlusHS fertiliser increased cane and sugar yields at Bungamayang SF. The highest sugar yield (5.60 t/ha) was obtained at 500 kg/ha of SiPlusHS, compared to the control treatment where no SiPlusHS was applied. There was no significant difference in sugar yields between treatments II and III.

The data also suggest that SiPlusHS could reduce phosphate fertiliser (treatment III), from 350 to 250 kg/ha of TSP. Indeed Mulyadi et al. (2005) reported that Si promotes the transformation of slightly soluble phosphates into plant-available phosphates. The increase in sugar yield with the addition of SiPlusHS was associated with a rise of sugar content (rendement) and cane yield. The average sugar yield at Bungamayang SF in 2007/2008 growing season was about 4.8 t/ha.

Table 2—Cane yield, rendement and sugar yield as affected by SiPlusHS treatments at Bungamayang SF.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Cane yield (t/ha)</th>
<th>Rendement (%)</th>
<th>Sugar yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>86.83 a</td>
<td>6.15 ab</td>
<td>5.34 ab</td>
</tr>
<tr>
<td>II</td>
<td>87.77 a</td>
<td>6.38 b</td>
<td>5.60 b</td>
</tr>
<tr>
<td>III</td>
<td>87.19 a</td>
<td>6.09 ab</td>
<td>5.51 ab</td>
</tr>
<tr>
<td>Control</td>
<td>86.51 a</td>
<td>5.78 a</td>
<td>5.00 a</td>
</tr>
</tbody>
</table>
Field experiments at Tjukir and Tersana Baru SF also showed similar results to the experiment at Bungamayang SF (Table 3). The application of 250 kg/ha of SiPlusHS at Tjukir SF increased sugar yield by 58.1%, whereas at Tersana Baru the increase was about 15.6%. The effect of Si on irrigated land on sugar yield was higher than that in the upland area. Soil moisture seems to play an important role in Si solubility (McKeague and Cline, 1963).

<table>
<thead>
<tr>
<th>Sugar factory area</th>
<th>SiPlusHS (kg/ha)</th>
<th>Cane yield (t/ha)</th>
<th>Rendement (%)</th>
<th>Sugar yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tjukir</td>
<td>0</td>
<td>103.98 a</td>
<td>8.04 a</td>
<td>8.36 a</td>
</tr>
<tr>
<td></td>
<td>250</td>
<td>157.76 b</td>
<td>8.38 b</td>
<td>13.22 b</td>
</tr>
<tr>
<td>Tersana Baru</td>
<td>0</td>
<td>85.61 a</td>
<td>7.02 a</td>
<td>6.01 a</td>
</tr>
<tr>
<td></td>
<td>250</td>
<td>87.53 a</td>
<td>7.94 b</td>
<td>6.95 b</td>
</tr>
</tbody>
</table>

Si fertiliser could also increase resistance of sugarcane to shoot and stem borers, as indicated in Table 4. In the control plots, shoot and stem borers attacked about 1.17% and 0.81% of sugarcane, respectively. The addition of Si could dramatically reduce shoot borer between 10–76% and stem borer between 48–79%. The presence of Si crystals in shoot and stem tissues of plants acts as a defence against feeding by insects having a rather fragile mandible. High levels of Si in tissues of sugarcane plant would confer a higher level of resistance to infections by pests as reported by Elawad et al. (1985). Toharisman et al. (2009b) also reported that the application of SiPlusHS at Jatitujuh, Karangsuwung and Subang SF areas could reduce shoot and stem borers by 75%.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Borer incidence</th>
<th>Shoot (%)</th>
<th>Stem (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0.91</td>
<td>0.23</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>0.28</td>
<td>0.17</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>1.05</td>
<td>0.42</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>1.17</td>
<td>0.81</td>
<td></td>
</tr>
</tbody>
</table>

At this time, the new Si fertiliser has been widely used in almost 1000 ha of sugarcane areas in Indonesia, including East Java, Central Java, West Java, Lampung and South Sumatera Provinces.

Acknowledgement

The authors would like to express their thanks to our stakeholders i.e. PTPN VII, PTPN X, PT RNI II and PT Pijar Nusa Pasifik.

REFERENCES


UNE NOUVELLE FORMULATION D’ENGRAIS A BASE DE SILICIUM POUR UNE MEILLEURE PRODUCTION DE CANNE A SUCRE

Par
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MOTS-CLES: Engrais à base de Silicium, Cendre de Chaudière, Scorie de Four, Substance humique, Productivité de la Canne à Sucre.

Résumé
LE SILICIUM (Si), un élément important pour la canne à sucre, est absorbé en quantités plus importantes que pour les autres éléments. Si améliore les rendements de la canne, augmente sa résistance aux stress biotiques et abiotiques, améliore la rigidité de sa tige et de ses feuilles et accroît la disponibilité en phosphore.

SiPlusHS a été formulé à partir de cendres provenant des chaudières de sucrerie, de scories de four, de phosphate de calcium naturel, de zéolite, d’acide oxalique et de substance humique. Cette formulation est constituée de granules de 3 à 5 mm de diamètre et contient 8 à 10% de Si soluble, 10 à 12% de phosphate soluble et 3 à 5% de substance humique. L’efficacité de cet engrais a été testée sur des cultures de canne à sucre en conditions irriguées et pluviales et sur des surfaces respectives de 1 et 2 ha. L’engrais fut épandu aux doses de 0, 250 et 500 kg/ha. Les résultats ont montré qu’une application de 250 kg/ha de SiPlusHS pouvait accroître les rendements canne de 2 à 52% et augmenter le tonnage de sucre /ha de 15 à 58%. Il n’y pas eu de différence significative entre les applications de 250 et 500 kg/ha de SiPlusHS. Dans certaines zones, SiPlusHS a pu diminuer significativement les attaques de borer de la tige. Récemment, cette nouvelle formulation a été testée sur environ 1000 ha dans différentes régions d’Indonésie.
CANE AND SUGAR PRODUCTION OF THE VARIETY ECU-01 WITH N, P, K, S AND MICRONUTRIENT APPLICATION IN PLANT CANE

By

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KEYWORDS: Sugarcane Fertilisation, Micronutrient Applications, ECU-01 Variety.

Abstract

In 2007, the Sugar Cane Research Centre of Ecuador (CINCAE) released their first variety, ECU-01, which has recorded good production throughout locations and ratoons. ECU-01 was grown commercially on 4000 ha in 2009. There is a need to study nutrient management of this variety by determining the effect of N, P, K, S and a mixture of micronutrients (Zn, Cu, Fe, Mn and B) to assess cane and sugar production. The experiment was established in Fluventic Haplustept, Vertic Ustropepts and Typic Haplustert soil types, which represent 59, 45 and 12% of the sugarcane area of Valdez, ECUDOS and San Carlos mills, respectively. Results showed that the highest cane yield (132 TCH) was produced at Valdez Mill, followed by ECUDOS Mill (108 TCH) and San Carlos Mill (84 TCH). The ECU-01 variety exhibited a significant response to 141 kg/ha N with an increase of 15, 40 and 30% tonne of cane/ha (TCH) and 21, 57 and 37% tonne of sugar/ha (TSH) compared to the control treatment (zero fertiliser) in ECUDOS, San Carlos and Valdez mills, respectively. On the other hand, in ECUDOS and Valdez mills, the dosage of 30 kg/ha of P\textsubscript{2}O\textsubscript{5} recorded the greatest production with 120–140 TCH and 15–17 TSH. The rate of 100 kg/ha of K\textsubscript{2}O increased TCH and TSH by 20% in ECUDOS mill and by 8% in San Carlos mill. In Valdez mill, K affected only the sugar concentration. There was no response to S application on TCH and TSH. Only in Valdez Mill, the addition of the micronutrient mixture produced an increase of 2.1 TSH and 11.0 TCH compared with the treatment without micronutrients. Our results have demonstrated that N is the most limiting nutrient in plant cane in all three locations. However, new data will be collected and analysed in first and second ratoon to determine fertilisation strategies for ECU-01 in the ratoon crops.

Introduction

As a result of 10 years of selection, the Sugarcane Research Center of Ecuador (CINCAE) released its first Ecuadorian variety, ECU-01, in July 2007. Sugarcane mills planted at least 600 ha of ECU-01 in 2008 (CINCAE, 2008) and established increase seed plots. In 2009, an increase to approximately 4000 ha was observed. Field trials of ECU-01 documented better response to fertilisation than variety Ragnar in a wide range of soil types and texture (CINCAE, 2004; CINCAE, 2005).

Cane production ranged between 90 to 110 tonnes of cane/ha (TCH), and 7.5 to 10.7 tonnes of sugar/ha (TSH) on plant cane using 80 N, 60 P\textsubscript{2}O\textsubscript{5} and 80 kg/ha of K\textsubscript{2}O. Whereas two ratoons recorded yields of 60 to 140 TCH and 6.0 to 12.5 TSH using 120 N, 100 P\textsubscript{2}O\textsubscript{5}; and 140 kg/ha of K\textsubscript{2}O, under traditional fertilisation rates used by sugarcane mills (CINCAE, 2008).

Studies on fertilisation with N, P and K have shown that nutrient recommendations depend on soil type, sugarcane variety and the number of ratoons (Quintero, 1995). Commercial production of variety Ragnar has been managed with applications of 120 and 150 kg N/ha in plant cane and
first ratoon, respectively (CINCAE, 2004). Preliminary observations with variety ECU-01 in trials at Valdez and San Carlos mills showed acceptable cane yields with low levels of N (40 and 80 kg/ha in plant cane and first ratoon, respectively) (CINCAE, 2007a). However, the sites did not represent soil types commonly used for sugarcane cultivation.

Soil maps drawn by three Ecuadorean sugarcane mills allowed us to choose representative zones to establish an experiment to study the effects of N, P (as P$_2$O$_5$), K (as K$_2$O), S and a micronutrient mixture on cane and sugar production in plant cane of variety ECU-01. This experiment would also allow the calculation of a statistical function which may identify the relationship between soil nutrients and sugar production in Ecuador.

Materials and methods

The experiment was planted at 3 locations: 1) on a Fluventic Haplustept (Valdez mill), 2) Vertic Ustropept (ECUDOS mill) and 3) Typic Haplustert (San Carlos mill) soil, representing 59%, 46% and 12% of the total sugarcane cultivation area. The treatment set up is shown in Table 1.

Table 1—Treatment layout in each location.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>N</th>
<th>P$_2$O$_5$</th>
<th>K$_2$O</th>
<th>S</th>
<th>Microelement mixture</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>kg ha$^{-1}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>35</td>
<td>90</td>
<td>200</td>
<td>60</td>
<td>NO</td>
</tr>
<tr>
<td>2</td>
<td>88</td>
<td>90</td>
<td>200</td>
<td>60</td>
<td>NO</td>
</tr>
<tr>
<td>3</td>
<td>141</td>
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<td>0</td>
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</table>

*This treatment is used to complete the high levels of K$_2$O and S in the analysis of K and S effect; also, to compare the level with the microelement mixture.

Applications of P, K, S and the micronutrient mixture were performed at the base of the row before planting the cane stools. All plots received 35 kg N/ha at sowing to adjust concentrations with the P sources (DAP). The remaining N was applied after 45 and 90 days. Micronutrients were combined in a mixture of 10, 10, 10, and 5 kg/ha of Zn, Mn, B and Cu, respectively. A randomised complete-block design with three replications was used for the experiment at each location; each experimental unit was formed by 6 rows, 10 m long, with 1.5 m between rows. Analysis of variance and linear or quadratic regressions for the rates of the nutrients were calculated with the INFOSTAT program (INFOSTAT, 2009).

Soil samples were taken at 30 cm depth before planting and fertilisation, and immediately after harvest. Soil P concentration, assimilate cations (K$^+$, Ca$^{++}$, Mg$^{++}$) and micronutrients (Zn, Mn,
Fe, Cu) was determined by a modified Olsen extraction. Leaf samples were taken at three and six months after sowing to determine N, P, K, Ca, and Mg concentrations using a mixture of sulfuric acid with selenium. Micronutrients (Zn, Mn, Cu and Fe) were determined by nitric and perchloric acid digestions. A nitric-perchloric acid and chloridric acid method was used for extracting sulfur. Boron was extracted by diluted sulfuric acid (CINCAE, 2007a).

The soil at the three locations was slightly acid (pH: 6.3–6.7), and Mn was between 10 and 20 ppm. Organic matter (OM) was < 1% in ECUDOS mill, while in San Carlos and Valdez mills OM was between 1.64 and 2.23%. The ECU DOS mill location had the lowest Ca (11–18 meq/100 g soil), Mg (4–13 meq/100 g soil) and Cu (4–8 ppm), but had high Zn and Fe content (3.8–6.3 ppm and 57–65 ppm, respectively). The San Carlos location had lower B concentration (1.0–1.3 ppm) than ECUDOS and Valdez mills (2.1–2.7 ppm). Soil P (10–12 ppm), K (0.09–0.18 meq/100) and S (11–16 ppm) concentrations were similar at the three sites.

Results and discussion

Soil response to the application of P2O5, K2O and S fertiliser

A relationship between the fertiliser applied and the soil mineral content was significant in the ECUDOS trial but not at the other locations (Figure 1). However, changes in P availability were found when P2O5 was applied to the soil. A similar trend was observed with applications of K2O and S fertilisers.

![Fig. 1. Relationship between P2O5, K2O and S application and soil contents of P (ppm), K (meq/100 g soil) and S (ppm) evaluated in three locations, 2008.](image-url)
Application of $P_2O_5$ and $S$ increased soil mineral content by 0.085 and 0.041 ppm, respectively in ECUDOS. Therefore, a dosage of 11.8 kg/ha of $P_2O_5$ and 24.4 kg/ha of $S$ increased soil mineral content one ppm each. However, in a previous study in a Vertic Tropaquept soil (sandy loam) from ECUDOS with variety Ragnar a dosage of 30 kg/ha of $P_2O_5$ led to 1 ppm of $P$ increase (Salazar et al., 2008).

Increasing $K$ into the soil solution was small in ECUDOS and San Carlos mills; however, a linear effect was shown for meq of $K/100$ g in the soil with a significant correlation ($R^2=0.70$). Similar effect was observed for $S$ in ECUDOS Mill (Figure 1).

This small response of the soil to applications of these nutrients might have been due to the type of colloidal material present in the soil; probably, there was loss of $K$ because it has less bonding strength to the cation exchange sites than Ca and Mg, or in the case of $P$ maybe there is a fixation of fertiliser phosphate by soil due to precipitation of phosphate compounds such as calcium phosphate (McLaren and Cameron, 1996).

**Cane and sugar production response to the application of nitrogen (N)**

At the three locations, applications of 141 kg/ha of $N$ recorded the highest sugar yields (TSH) (Figure 2). At this rate, in San Carlos and ECUDOS mills, TCH was low (89 and 101 TCH) whereas sugar production was high (11 and 13 TSH, respectively), due to higher sugar concentrations (12.1 and 12.9% pol, in that order). At the Valdez Mill location, yields of 20 TSH were obtained from the highest tonnage of cane (154 TCH) (Figure 2). However, another study (CINCAE, 2007b) showed that ECU-01 can have good yields with only 40 kg/ha of $N$ applied. Nevertheless, that study was conducted in soils with high organic matter (SOM) concentration (2.7%); whereas, in the present study, SOM was only 0.7 to 0.9%. Some studies carried out by Quintero (1995) and Cassman et al. (2002) determined that sugarcane $N$ needs depended on soil type, number of ratoons, and variety; with SOM concentration a key factor affecting the response to $N$ application.
Cane and sugar production response to the application of \( \text{P}_2\text{O}_5 \), \( \text{K}_2\text{O} \) and S

The effect of P, K and S application was different at each location. In ECUDOS and Valdez mills, the application of 30 kg/ha of \( \text{P}_2\text{O}_5 \) increased 7 and 4 TCH and 1.5 and 0.8 TSH compared to 0 application of P (control). A study carried out by CINCAE on Inceptisol and Vertisol soils (sandy loam) showed that 30 or 60 kg/ha of \( \text{P}_2\text{O}_5 \) were enough to achieve maximum sugar yields (Salazar et al., 2008). There was no effect of P in San Carlos mill.

Application of 100 kg/ha of \( \text{K}_2\text{O} \) increased from 100 TCH in the 0 K control treatment to 120 TCH in ECUDOS mill; while, in San Carlos mill, the increase was from 81 to 88 TCH. At this rate, the boost of TSH was higher (20%) in ECUDOS mill than in San Carlos mill (8%). Only, in Valdez mill, the use of \( \text{K}_2\text{O} \) affected sugar concentration from 11.6% pol in the 0 K control treatment to 12.7 and 13.5% pol in the rates of 50 and 100 kg/ha, respectively.

Application of S did not lead to significant differences in cane production at the three locations. This could be due to the high S concentration in the soil (ECUDOS mill, 26–47.3 ppm, San Carlos and Valdez Mills, 11–20 ppm). However, at Valdez Mill, 30 kg/ha of S increased sugar content from 12.3% pol in the 0 S treatment to 13.5% pol. Similar results were observed by Quintero (1995) on Vertisol, Mollisol and Inceptisol soils where no response to S application was found, but a slight increase of sugar content in the juice was observed.

The micronutrient mixture increased yields by 15 TCH and 2 TSH at the Valdez Mill. However, leaf tissue concentrations and plant removal of Zn, Cu, Fe, Mn and B from the soil were not different in the micronutrient mixture treatment compared to zero application of microelement mixture (data not shown), suggesting that there was sufficient micronutrient concentration for sugarcane growth in the soil solution. Therefore, ranges for soil concentration were established at the three locations for Cu (3.0–8.0 ppm), B (1.0–2.8ppm), Fe (14–65 ppm), Mn (4.0–13.0 ppm) and Zn (0.3–0.5).

Conclusions

Cane and sugar production of variety ECU-01 depended on the soil type and crop management in the three locations. The highest cane yields were recorded with the application of 141, 30, 100 and 30 kg/ha of N, \( \text{P}_2\text{O}_5 \), \( \text{K}_2\text{O} \) and S respectively. Nitrogen applications increased both cane and sugar production at the three sites, while responses of tonnage of cane, sugar and % pol to P, K and S were different at each site.

This study has confirmed that N was the most limiting nutrient for plant cane at three mills in Ecuador. Data will be analysed for the first and second ratoon to determine cane yield response to nutrient application in the ratoon crops.

The rate of 100 kg/ha of \( \text{K}_2\text{O} \) increased TCH and TSH by 20% in ECUDOS mill and by 8% in San Carlos mill. In Valdez mill, K affected only the sugar concentration. There was no response to S application on TCH and TSH.

REFERENCES


**PRODUCTION DE CANNE ET DE SUCRE PAR LA VARIETE ECU_01 AVEC DES APPLICATIONS EN CANNE PLANTEE DE N, P, K, S ET D'OLOGEOELMENTS**

Par

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MOTS-CLES: Fertilisation de la Canne à Sucre, Applications d'Oligoéléments, Variété ECU-01.

Résumé

En 2007, Le centre de recherche sur la Canne à Sucre en Equateur (CINCAE) a libéré sa première variété ECU-01, qui s’est révélée très productive dans toutes les zones et repousses. La variété ECU-01 a été cultivée commercialement sur 4000 ha en 2009. La nutrition de cette variété devait être déterminée en étudiant les effets de N, P, K, S et d’un mélange d’oligoéléments (Zn, Cu, Fe, Mn et B) sur la production de ECU-01. L’expérimentation fut réalisée sur les types de sol Fluventic Haplustept, Vertic Ustropepts et Typic Haplustert, qui représentent respectivement 59, 45 et 12% de la surface en canne à sucre des usines de Valdes, Ecuadors et San Carlos. Les résultats montrèrent que les rendements les plus élevés (132 TCH) ont été produits à l’usine de Valdes, suivis par l’usine d’Ecuadors (108 TCH) et San Carlos (84 TCH). La variété ECU-01 a montré une réponse significative à 141 kg/ha d’N avec des accroissements respectifs de 15, 40 et 30% en tonne de canne /ha (TCH) et de 21, 57 et 37% de tonne de sucre /ha (TSH) comparé au témoin (aucun engrais) sur les plantations des usines d’Ecuadors, Calos et Valdes. D’autre part, sur les plantations des usines d’Ecuadors et Valdes, la dose de 30 kg/ha de P₂O₅ a produit le plus avec 120–140 TCH et 1–17 TSH. La dose de 100 kg/ha de K a augmenté TCH et TSH de 20% sur l’usine d’Ecuadors et de 8% à San...
Carlos. A l’usine de Valdes, K a affecté uniquement la teneur en sucre. Il n’y a pas de réponse en TCH et TSH aux applications de S. A l’usine de Valdes, seulement, l’addition d’un mélange d’oligoéléments a produit une augmentation de 2.1 TSH et 11.0 TCH comparé au témoin sans oligoéléments. Ces résultats ont montré que N est l’élément minéral le plus limitant en canne plantée sur tous les sites. Cependant, d’autres données seront collectées et analysées en première et seconde repousse afin de déterminer les stratégies de fertilisation d’ECU-01 en repousses.

PRODUCCIÓN DE CAÑA Y AZÚCAR DE LA VARIEDAD ECU-01 CON LA APLICACIÓN DE N, P, K, S Y UNA MEZCLA DE MICROELEMENTOS EN CAÑA PLANTA

Por

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PALABRAS CLAVES: Fertilización de Caña de Azúcar, Aplicación de Micronutrientes, Variedad ECU-01.

Resumen

EN EL 2007, el Centro de Investigación de Caña de Azúcar del Ecuador (CINCAE) liberó la primera variedad llamada ECU-01, la cual ha presentado buena producción en diferentes localidades y socas. Desde su lanzamiento el área comercial se han incrementado hasta llegar a 4000 ha\(^{-1}\) en el 2009. Hay una necesidad para estudiar el manejo de nutrientes determinando el efecto de N, P (as P\(_2\)O\(_5\)), K (as K\(_2\)O), S y una mezcla de micronutrientes (Zn, Cu, Fe, Mn y B) en la producción de caña y azúcar. El experimento fue establecido en suelos del tipo Fluventic Haplustept, Vertic Ustrovepts y Typic Haplustert, los cuales representan 59, 45 y 12% del total del área cañera de los ingenios Valdez, ECUDOS y San Carlos, respectivamente. El mayor tonelaje de caña por hectárea (TCH) presentó el ingenio Valdez (132 TCH), seguido por ECUDOS (108 TCH) y San Carlos con 84 TCH. La variedad ECU-01 presentó una respuesta significativa a la aplicación de 141 kg/ha de N con un incremento de 15, 40 y 30% de TCH y 21, 57 y 37 % de TAH comparado con el tratamiento control (cero fertilización) en ECUDOS, San Carlos y Valdez, respectivamente. En los ingenios ECUDOS y Valdez, la dosis de 30 kg/ha de P\(_2\)O\(_5\) tuvo la más alta producción de caña y azúcar (120–140 TCH y 15–17 TAH). La aplicación de 100 kg/ha de K\(_2\)O incremento 20% del tonelaje de cana y azúcar en el ingenio ECUDOS y 8 % en el Ingenio San Carlos. En Valdez el K afectó solamente a la concentración de azúcar. No hubo respuesta a la aplicación de S en el tonelaje de caña y azúcar por hectárea. Únicamente, en el ingenio Valdez, el uso de la mezcla de microelementos produjo un amento de 2.1 TAH y 11 TCH comparado con el tratamiento sin la aplicación de microelementos. Los resultados demostraron que el N es el nutriente más limitante en la producción de caña planta en las tres localidades. Sin embargo, nueva información será colectada y analizada en la primera y segunda soca para determinar estrategias de fertilización en las socas.
AGRONOMIC MANAGEMENT OF INTERCROPPING IN SUGARCANE AND ITS ECONOMIC IMPLICATIONS

By

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KEYWORDS: Number of Millable Canes, Stalk Population, Cane Yield, Intercrops, Economics.

Abstract

GROWTH rate of sugarcane during the initial stages is rather slow with the low canopy coverage, and it is possible to exploit the potential of the cropping system by adjusting crop geometry and utilisation of inter-crops. Therefore, a field experiment was conducted to assess the economic benefits of intercrops with different planting configurations in sugarcane. Dual-row (60–120–60 cm) and single-row (90 cm) methods of planting were deployed as main plots and intercrops comprising sunnhemp, maize, cowpea (green manure), soybean (inter-crop), peanut, potato and french bean were treated as subplots. Planting systems did not alter significantly the number of millable canes (NMC) or cane yield. However, sunnhemp, cowpea grown and soybean recorded higher NMC (92 080, 89 830 and 87 830/ha respectively) than cane alone (85 910/ha), while maize intercropping gave 68 880 NMC and the sugarcane yields were 111.1, 109.1, 106.9 and 70.8 t/ha, respectively for the 4 inter-crops and 107.4 t/ha for cane alone. Higher cane yields are attributed to the optimum shoot population which later on converted higher NMC and cane weight due to in situ incorporation of green manure and its further decomposition in building organic matter content of soil. Detrimental effect on NMC and cane yield was noticed due to intercropping of maize in sugarcane. Compared to the normal single row configuration, dual-row planting with the same cost of cultivation improved B:C ratio from 2.17 to 2:76, due to higher cane yields. As a result of the grain yield of soybean (1.5 t/ha) and lower cost of production in soybean inter-cropping, this strategy recorded the highest net return (Rs68, 336/ha) with B:C ratio of 3.21 compared to other inter-crops. Conversely, although maize and potato yields were higher, these treatments produced lower net income and B: C ratios due to the reduction in cane yield. Post-cane harvest data indicate that inter-cropping has a positive effect on the chemical properties of soil.

Introduction

Sugarcane is one of the more important commercial crops of India and is cultivated with row spacing of 75–90 cm. The growth rate of sugarcane during its initial stages (90–100 days) is rather slow, with the leaf canopy providing sufficient uncovered area for growing of other crops. Inter-cropping in sugarcane with short duration crops is agronomically advantageous and could provide additional revenue (Ayyer, 1963). Further, alterations in planting methods that do not compromise cane yields will provide additional opportunity to exploit the potential of the crop by growing intercrops.

Sugarcane, as a long duration crop, gives income about a year after planting, and there is a dire need to diversify the cropping system to provide shorter-term income by introducing other crops, either as sequential or inter-cropping strategies, especially for farmers having smaller land holdings. Jamuna et al. (2007) indicated that the cane yields were not affected by dual-row planting,
and cane yields were higher with the dual-row system than for wider rows. Devaraj and Shanmugsundaram (1987) observed that cane yield was improved by adopting dual rows of 40–80 cm spacing compared with conventional 80 cm row planting and that the dual-row system allowed growth of intercrops. Therefore, a study was initiated to study the effect of growth and yield attributes, yield of cane and sugar, economics and chemical properties of soil when sugarcane was grown in different row configurations and with or without intercrops.

Material and methods

A field experiment was conducted at the K.J. Somaiya’s Karnataka Institute of Applied Agricultural Research, in India during 1997–98. The vertisol soil had available nitrogen, phosphorus and potassium values of 285, 7.3 and 0.419 kg/ha, mg/kg and cmol/kg respectively and a soil pH of 8.1. The field investigation consisted of two planting methods viz., ridge and furrow planting (90 cm) and dual rows of 60–120–60 cm as main treatments and seven intercrops viz., sunnhemp (green manure), maize, cowpea (green manure), soybean, peanut, potato, french bean and sole sugarcane as subplots in a split plot design replicated four times. An early maturing CoC671 cultivar of sugarcane was used for experimentation. Intercrops viz. sunnhemp, maize, cowpea, soybean, peanut, potato and french bean were sown simultaneously at the time of sugarcane planting. Sunnhemp, cowpea, soybean, peanut, maize and potato were sown in a row proportion of 1:1 in single rows of cane. In the case of dual rows, sunnhemp, cowpea, soybean, peanut and french bean were sown in row proportion of 2:3, while maize and potato were sown in a row proportion of 2:2. Sunnhemp and cowpea were incorporated at 45 days after planting of sugarcane. Yields of different intercrops were recorded at harvest. Sugarcane growth, yield attributes, yield and juice quality parameters were recorded. Soil was analysed as per the standard procedure after harvesting of sugarcane. Gross income, cultivation cost, net return and B:C ratios were calculated for the different systems. Statistical analysis was done by using Duncan Multiple range Test (DMRT) and data were presented in a homogeneous group.

Results and discussion

Experimental results reveal that different planting configurations had no significant impact (p=0.05) on growth and cane yield attributes viz., single cane weight, girth of cane, length of internodes, number of internodes, plant height, NMC, and cane and sugar yields. Of the intercropping systems, sunnhemp, cowpea, soybean, potato, french bean and sugarcane alone treatments gave superior single stalk weight compared to the maize intercropping system (Table 1).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Single cane weight (kg)</th>
<th>Girth of cane (cm)</th>
<th>Length of internode (cm)</th>
<th>No. of internode (cm)</th>
<th>Plant height (cm)</th>
<th>NMC ('000/ha.)</th>
<th>Cane yield (t/ha)</th>
<th>Sugar yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planting methods</td>
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<tr>
<td>P1. Normal method</td>
<td>1.2 a</td>
<td>2.9 a</td>
<td>10.42a</td>
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<td>170.9 a</td>
<td>84.7 a</td>
<td>101.2 a</td>
<td>11.2 a</td>
</tr>
<tr>
<td>P2. Paired row</td>
<td>1.2 a</td>
<td>2.9 a</td>
<td>10.53a</td>
<td>21.6 a</td>
<td>178.1 a</td>
<td>85.7 a</td>
<td>102.6 a</td>
<td>11.3 a</td>
</tr>
<tr>
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<td>NS</td>
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<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
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<tr>
<td>T1 Cane + sunnhemp</td>
<td>1.3 a</td>
<td>3.0 a</td>
<td>11.1 a</td>
<td>22.3 a</td>
<td>182.1 a</td>
<td>92.08 a</td>
<td>111.1 a</td>
<td>12.5 a</td>
</tr>
<tr>
<td>T2 Cane + maize</td>
<td>1.0 b</td>
<td>2.9 a</td>
<td>9.3 c</td>
<td>19.2 a</td>
<td>161.4 a</td>
<td>68.88 c</td>
<td>70.8 b</td>
<td>7.6 b</td>
</tr>
<tr>
<td>T3 Cane + cowpea</td>
<td>1.3 a</td>
<td>3.0 a</td>
<td>10.9 ab</td>
<td>22.6 a</td>
<td>180.1 a</td>
<td>89.83 ab</td>
<td>109.1 a</td>
<td>12.3 a</td>
</tr>
<tr>
<td>T4 Cane + soybean</td>
<td>1.2 a</td>
<td>2.9 a</td>
<td>10.6 ab</td>
<td>22.1 a</td>
<td>177.4 a</td>
<td>87.83 ab</td>
<td>106.9 a</td>
<td>12.1 a</td>
</tr>
<tr>
<td>T5 Cane + peanut</td>
<td>1.2 a</td>
<td>2.90 a</td>
<td>10.2 b</td>
<td>20.5 a</td>
<td>170.1 a</td>
<td>83.70 b</td>
<td>100.7 a</td>
<td>10.9 a</td>
</tr>
<tr>
<td>T6 Cane + potato</td>
<td>1.2 a</td>
<td>2.8 a</td>
<td>10.4 ab</td>
<td>20.6 a</td>
<td>169.3 a</td>
<td>85.53 b</td>
<td>103.9 a</td>
<td>11.5 a</td>
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<tr>
<td>T7 Cane + French bean</td>
<td>1.2 a</td>
<td>2.9 a</td>
<td>10.6 ab</td>
<td>21.3 a</td>
<td>177.0 a</td>
<td>87.57 ab</td>
<td>105.5 a</td>
<td>11.8 a</td>
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<tr>
<td>T8 Cane alone</td>
<td>1.3 a</td>
<td>2.9 a</td>
<td>10.8 ab</td>
<td>22.3 a</td>
<td>178.7 a</td>
<td>86.02 b</td>
<td>107.4 a</td>
<td>11.6 a</td>
</tr>
<tr>
<td>LSD(p=0.05)</td>
<td>0.15</td>
<td>NS</td>
<td>0.76</td>
<td>NS</td>
<td>NS</td>
<td>5.49</td>
<td>12.37</td>
<td>1.88</td>
</tr>
</tbody>
</table>

Numbers in each column followed by the same letter are not significantly different at p = 0.05
DAP = Days after planting
However, cane girth, number of internodes and plant height were unaltered in the different inter-cropping systems. However, sunnhemp and cowpea significantly enhanced cane height and number of internodes over other systems.

Similarly the NMC and cane yield were significantly higher (p=0.05) in sunnhemp, cowpea and soybean inter-cropping systems and the cane alone control compared to maize inter-cropping (Table 1). Higher cane yield was obtained due to the optimum shoot population which eventually helped in producing NMC values and in situ incorporation of green manure. Incorporation of green manure and its further decomposition in building organic matter of soil and uptake of nutrients which led to higher cane weight, accomplished with better cane girth and internodal length as observed in the findings of Kathiresan and Ayyamperumal (1996).

Yield of the sugar alone system was similar to that of cane yield in the different intercropping systems, with the exception of the cane-maize system (Table 1). Intercropping of peanut, potato and french bean in sugarcane had no impact on growth parameters and yield of sugarcane, and these results are consistent with the opinion expressed by Srinivas (1996). Sugarcane yield reduction from 107.39 t/ha in the cane alone system to 70.82 t/ha with maize inter-cropping indicates that maize adversely affected the various growth and yield parameters of sugarcane.

**Economics**

The net returns were higher in dual row planting (Rs58,534/ha) compared to single rows (Rs56,628/ha) due to increased yields for the same cost of production (Table 2). Similarly, the B:C ratio in dual rows was higher by 0.29 compared to the single-row method of planting. Among the intercropping systems, sugarcane plus soybean gave highest gross income (Rs99,248/ha), net income (Rs68,336/ha) and B:C ratio (3.21) compared to other all treatments.

The highest net income in sugarcane inter-cropped with soybean was mainly due to higher cane yield (111.09 t/ha) coupled with soybean grain yield of soybean 1.5 t/ha. Similar findings were reported by Biradar *et al.* (1995). Although maize yield were higher compared to other inter-crops, the net income was the least due to drastic reduction in cane yields.

**Table 2—Economics of planting methods and intercropping systems in sugarcane.**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Intercrops yield t/ha</th>
<th>Gross income (Rs.)</th>
<th>Cost of cultivation (Rs/ha)</th>
<th>Net return (Rs/ha)</th>
<th>B.C.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Cane</td>
<td>Intercrops</td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Planting methods</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P1. Normal method</td>
<td>3.6</td>
<td>89,836</td>
<td>27,710</td>
<td>5498</td>
<td>33,208</td>
</tr>
<tr>
<td>P2. Paired row</td>
<td>4.2</td>
<td>91,743</td>
<td>27,710</td>
<td>5498</td>
<td>33,208</td>
</tr>
<tr>
<td>Intercropping systems</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1 Cane + sunnhemp</td>
<td>7.5</td>
<td>89,924</td>
<td>27,710</td>
<td>2080</td>
<td>29,790</td>
</tr>
<tr>
<td>T2 Cane + maize</td>
<td>2.9</td>
<td>68,142</td>
<td>27,710</td>
<td>4058</td>
<td>31,768</td>
</tr>
<tr>
<td>T3 Cane + cowpea</td>
<td>6.0</td>
<td>88,221</td>
<td>27,710</td>
<td>1910</td>
<td>29,620</td>
</tr>
<tr>
<td>T4 Cane + soybean</td>
<td>1.5</td>
<td>99,248</td>
<td>27,710</td>
<td>3202</td>
<td>30,912</td>
</tr>
<tr>
<td>T5 Cane + peanut</td>
<td>0.9</td>
<td>90,014</td>
<td>27,710</td>
<td>4569</td>
<td>32,299</td>
</tr>
<tr>
<td>T6 Cane + Potato</td>
<td>6.8</td>
<td>110,319</td>
<td>27,710</td>
<td>23,103</td>
<td>50,813</td>
</tr>
<tr>
<td>T7 Cane + French bean</td>
<td>0.8</td>
<td>94,540</td>
<td>27,710</td>
<td>5049</td>
<td>32,759</td>
</tr>
<tr>
<td>T8 Cane alone</td>
<td>–</td>
<td>85,910</td>
<td>27,710</td>
<td>–</td>
<td>27,710</td>
</tr>
</tbody>
</table>

**Chemical properties of soil**

There was no significant difference observed in organic carbon content across planting methods or intercropping systems or their interactions (Table 3). Similar results were observed by Pandit and Sinha (1981) due to incorporation of cowpea. Available nitrogen, phosphorus, potash of the soil after harvest of sugarcane recorded non-significant results with respect to planting methods.
Among the inter-cropping systems, sunnhemp, cowpea, soybean, peanut, potato and french bean showed significantly \((p = 0.05)\) higher residual available nitrogen, phosphorus and potassium compared to maize inter-cropping system. Shankaraiah and Nagaraju (1997) showed improved available nitrogen, phosphorus and potassium due to intercropping and incorporation of legumes.

**Table 3**—Chemical properties of soil as influenced by planting methods and intercropping in sugarcane.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Available nitrogen (kg/ha)</th>
<th>Available phosphorus (kg/ha)</th>
<th>Available potassium (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planting methods</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P1. Normal method</td>
<td>299.1 a</td>
<td>21.5 a</td>
<td>330.5 a</td>
</tr>
<tr>
<td>P2. Paired row</td>
<td>301.5 a</td>
<td>22.9 a</td>
<td>333.8 a</td>
</tr>
<tr>
<td>LSD(p=0.05)</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Intercropping systems</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1 Cane + sunnhemp</td>
<td>325.5 a</td>
<td>29.9 a</td>
<td>337.5 a</td>
</tr>
<tr>
<td>T2 Cane + maize</td>
<td>272.4 b</td>
<td>13.6 b</td>
<td>324.2 b</td>
</tr>
<tr>
<td>T3 Cane + cowpea</td>
<td>318.1 a</td>
<td>28.0 a</td>
<td>336.4 a</td>
</tr>
<tr>
<td>T4 Cane + soybean</td>
<td>312.4 a</td>
<td>25. a</td>
<td>335.2 a</td>
</tr>
<tr>
<td>T5 Cane + peanut</td>
<td>300.1 a</td>
<td>23.4 a</td>
<td>334.2 a</td>
</tr>
<tr>
<td>T6 Cane + Potato</td>
<td>300.0 a</td>
<td>24.0 a</td>
<td>334.2 a</td>
</tr>
<tr>
<td>T7 Cane + French bean</td>
<td>309.3 a</td>
<td>24.9 a</td>
<td>335.2 a</td>
</tr>
<tr>
<td>T8 Cane alone</td>
<td>271.2 b</td>
<td>13.5 b</td>
<td>325.5 b</td>
</tr>
<tr>
<td>LSD(p=0.05)</td>
<td>26.14</td>
<td>8.21</td>
<td>3.82</td>
</tr>
</tbody>
</table>

Numbers in each column followed by the same letter are not significantly different at \(p=0.05\)

**Conclusions**

The dual-row system was preferred over single rows due to its higher cane and sugar yield. Additional advantages of obtaining inter-cropping yield can also be exploited. Growing of soybean in sugarcane inter-cropping and incorporation of *in situ* green manures like sunnhemp and cowpea recorded higher yield and also improved the soil chemical properties to help to sustain yield of sugarcane. Maize and potato are not ideal inter-crops in sugarcane.

**Acknowledgements**

The author acknowledges Shri. Samir S. Somaiya, Executive Director, Somaiya Group, Mumbai for help in carrying out the project and the encouragements from Chairman of Karnataka Sugar Institute and Secretary, Commerce and Industries, Commissioner for Cane Development and Director of Sugar, Government of Karnataka and Director, Karnataka Sugar Institute, Belgaum.

**REFERENCES**


CONDUITE AGRONOMIQUE DE CULTURES INTERCALAIRES EN CANNE A SUCRE ET SES IMPLICATIONS ECONOMIQUES

Par

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MOTS-CLES: Nombre de Tiges Usinables, Population de Tiges, Cultures Intercalaires, Economie.

Résumé
LA CROISSANCE de la canne à sucre pendant les premiers stades est plutôt lente avec un faible taux de couverture, et il est alors possible d’exploiter le potentiel du système cultural en adaptant sa géométrie pour des cultures intercalaires. Aussi, un essai en champ a-t-il été conduit pour évaluer les bénéfices économiques de cultures intercalaires avec diverses configurations de plantation en culture de canne à sucre. Des modes de plantation, rang jumelé (60–120–60 cm) et rang simple (90 cm) ont constitué les traitements principaux et des cultures intercalaires comme la crotalaire, le maïs, le niébé (engrais vert), le soja (culture intercalaire), l’arachide, la pomme de terre et le haricot vert, ont constitué les traitements secondaires. Alors que la crotalaire, le niébé et le soja ont produit plus de tiges usinables (NMC) (respectivement 92 080, 89 830 et 87 830/ha) que la canne seule (85 910/ha), la culture intercalaire de maïs a donné 68 880 NMC. Les rendements de canne ont été de 111.1, 109.1, 106.9 et 70.8 t/ha, respectivement pour les 4 cultures intercalaires, et de 107.4 t/ha pour la canne seule. Les rendements les plus élevés en canne sont attribués aux plus forts taux de tallage, donnant plus tard le plus de tiges usinables et les plus forts rendements en raison de l’incorporation de l’engrais vert et à sa décomposition ultérieure en matière organique organique du sol. Comparé au système en simple rang, le rang jumelé, avec le même coût de production a augmenté le ratio B:C (Bénéfice/Coût) de 2.17 à 2.76, en raison des plus forts rendements canne. En raison de la récolte en grain du soja (1.5 t/ha) et du plus bas coût de production de cette culture intercalaire, en comparaison avec les autres cultures intercalaires, cette itinéraire a enregistré le plus fort revenu (Rs68,336/ha) avec un B:C ratio de 3.21. Inversement, quoique le maïs et les pommes de terre aient eu des rendements plus élevés, ces cultures ont produit les revenus nets et ratios B:C les plus faibles en raison de la réduction des rendements canne. Les données après récolte indiquent que les cultures intercalaires ont eu un effet positif sur les propriétés chimiques du sol.
EL MANEJO AGRONOMICO DEL CULTIVO INTERCALADO EN CANA DE AZUCAR Y SUS IMPLICACIONES ECONOMICAS

Por

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Resumen

EL INDICE de crecimiento de la caña de azúcar durante los primeros estadios es más bien lento, con poca cobertura del follaje y se puede aprovechar el potencial del sistema intercalado, ajustando la geometría del cultivo y la utilización de cultivos intercalados. De este modo, se condujo un experimento para evaluar los beneficios económicos de los cultivos intercalados con diversas configuraciones de siembra en caña de azúcar. Se establecieron parcelas grandes con método de siembra de surco doble (60–120–60 cm) y de surco simple (0.9 cm), y como parcela pequeña cultivos intercalados como cáñamo, maíz, caupí (abono verde), soya (cultivo intercalado), maní, papa y judías. Los sistemas de siembra no alteraron significativamente el número de tallos molederos (NMC) o el rendimiento de caña. Sin embargo, al cultivar cáñamo, caupí y soya se registró un aumento en NMC (92 080, 89 830 y 87 830/ha respectivamente) que al sembrar caña sola (85 910/ha), mientras el maíz intercalado produjo 68 880 NMC y los rendimientos de caña con los cuatro cultivos intercalados fueron 111.1, 109.1, 106.9 y 70.8 ton/ha, respectivamente y 107.4 t/ha para caña de azúcar sola. Los rendimientos más altos de caña se atribuyen a la población óptima de tallos que consecutivamente se convirtieron en un NMC más alto y mayor peso de caña, esto debido a la incorporación in situ de abono verde y su posterior descomposición en materia orgánica del suelo. Se observó un efecto detrimental en NMC y rendimiento de caña al intercalar maíz con caña de azúcar. Al comparar el surco simple con la siembra en surco doble, este último mejoró la relación B:C de 2.17 a 2.76, por los mayores rendimientos de caña. Como resultado del rendimiento en granos de soya (1.5 ton/ha) y su menor costo de producción, la estrategia de intercalar soya reportó el mayor retorno (Rs68, 336/ha) con una relación B:C de 3.2, comparada con otros cultivos intercalados. Por otro lado, a pesar de que el maíz y la papa produjeron mayores rendimientos, estos tratamientos reportaron menor ingreso neto y menor relación B:C, debido a la reducción en rendimiento de caña. Los datos post cosecha indican que el cultivo intercalado tiene un efecto positivo sobre las propiedades químicas del suelo.
BREEDING RESISTANT SUGARCANE FOR MANAGING THE STEM BORER
DIATRAEA SACCHARALIS: PROGRESS AND PROSPECTS FOR LOUISIANA

By

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KEYWORDS: Insect Resistance, Breeding Strategy.

Abstract

THE STEM borer, \textit{Diatraea saccharalis} (F.), is an important insect pest of sugarcane in Louisiana. Growing resistant varieties is a component of the Integrated Pest Management Program as practised in Louisiana for managing this insect; however, the release of stem borer resistant varieties has been intermittent. In 1986, researchers at the USDA, Agricultural Research Service (ARS) and LSU Agricultural Center – the two breeding programs in Louisiana – initiated an effort to increase stem borer resistance without encumbering the Louisiana sugarcane variety program (LSVP) with an additional selection trait. In this approach, clones with high levels of stem borer resistance are developed at the USDA, ARS in Houma via a recurrent selection program for borer resistance (RSB) and these resistant clones are used as parents in crossing. Advancement data from the Louisiana State University AgCenter’s sugarcane breeding program were evaluated to determine our success in incorporating the new resistant germplasm into the progeny advancing through this program. A statistical test using the cumulative logit model showed non-significant difference (P > 0.05) in advancement rates of clones between the RSB and non-RSB families. However, because of fewer seedlings derived from crosses with at least one RSB parent, very few clones were given permanent variety assignments from the RSB population; only seven in the 1991 to 2002 series. A simulation study was done to determine the effect of increasing selection rates on recovery of RSB clones at the different stages of the breeding program. The cumulative logit model showed that increasing selection rates from Stage I to Stage II will result in a significant increase in the number of RSB clones assigned a variety designation. From this study we propose that the number of resistant crosses be increased and the selection rate of RSB crosses at Stage I be doubled to 13%.

Introduction

Host plant resistance is an important component in the integrated pest management (IPM) of insect pests. Host plant resistance costs the grower little and is compatible with other IPM control tactics (Adkisson and Dyck, 1980). However, unlike diseases that are generally managed with resistant varieties, insect pests of sugarcane are frequently managed by biological control or with insecticides. As a result, sugarcane breeding efforts for insect resistance lag behind efforts devoted to breeding for disease resistance. In fact, susceptibility to diseases has been one of the major incentives for setting up plant breeding programs (Walker, 1987).
Breeding for insect resistance in sugarcane, as with many traits, is likely to be hindered by the complexity of the sugarcane genome and the absence of simply inherited traits (Hogarth, 1987). Several studies have been conducted on the quantitative inheritance of disease resistance in sugarcane (Hogarth et al., 1983 and Hogarth et al., 1993), but few have been conducted for insect resistance. Viator and Henderson (1971) found sugarcane borer resistance to be quantitative in nature, but provided no measures of genetic variation, heritability, or potential gain from selection. White et al. (2001) reported that narrow-sense heritabilities for sugarcane borer damage ratings and for percent damaged internodes were high and comparable in magnitude, $h^2=0.73$ and $h^2=0.76$ respectively, while Milligan et al. (2003) reported broad-sense heritabilities for percent damaged internodes ranging from $H=0.29$ to $H=0.62$. Viator and Henderson (1971), White et al. (2001), and Kimbeng et al. (2006) all presented evidence of a strong additive component to the inheritance of sugarcane borer resistance.

Findings from genetic studies indicate that sugarcane borer resistance could be reliably increased by diligently selecting and crossing among the most resistant parents and then focusing selection on progeny within these crosses. Methods required for the screening and evaluation for resistance have also been established. White (1993) and White et al. (1996) discussed screening and evaluation procedures as well as a breeding strategy for increasing levels of sugarcane borer resistance in sugarcane parental populations.

A final, yet critical aspect of breeding for sugarcane borer resistance is genotypic correlations. When selecting rigorously for a few characters, it is important to understand the correlated responses on other important traits. Milligan et al. (2003) reported low to moderate broad-sense genetic correlations among five stem borer damage measures (bored internodes, pupation success, moth production, and damage rating) and the yield components (sucrose yield, cane yield, sucrose content, stalk number) from an unselected population. All but one of the damage measures were negatively correlated with sugar yields. Fibre was not determined in this study. White et al. (2006) found that varieties with pith were significantly less damaged than those without pith. The authors found that varieties with pith also have higher stalk fibre; a trait that can contribute to lower sugar yields and decreased throughput in raw sugar factories.

The above discussion addresses critical aspects for developing a breeding strategy for sugarcane borer resistance. After initiating a recurrent selection program to identify clones with borer resistance and utilising these as parents, we have become increasingly concerned as to the quality of these clones as parents as no progeny from this material have been released to the grower. Here we summarise 22 years of advancement records from the Louisiana University AgCenter’s Sugarcane Variety Program where at least one parent of the bi-parental cross involved a sugarcane borer resistant parent. Drawing from these records, our object was to propose a strategy for increasing the number of selections derived from sugarcane borer resistance parents. Doing so increases the chances of a selection being made or a clone being recycled as a parent for crossing that possesses insect resistance and desirable agronomic characters.

**Materials and methods**

**Recurrent Selection Borer Resistance Program (RSB)**

A recurrent selection program for developing sugarcane borer resistant parental clones was started at the USDA, Agricultural Research Service (ARS) in 1986. A summary of procedures and results from the first 10 years of recurrent selection can be found in White et al. (1996). These authors report 19 parental clones identified as resistant to the sugarcane borer. By 2008, the number of resistant parental clones had increased to 76; of these, 16 (22%) are currently being used as parents in the Louisiana sugarcane variety program (LSVP). This program is a joint effort between the USDA, ARS, the Louisiana State University AgCenter and the American Sugar Cane League of the U.S.A., Inc.
Incorporation of sugarcane borer resistance from the RSB program

The 1989–1990 crossing campaign was our first opportunity to breed with clones derived from the RSB program. The seedlings derived from these crosses were selected and advanced following the procedures used by the USDA, ARS and the LSU AgCenter’s breeding programs. Bischoff and Gravois (2004) provide a detailed summary of the LSVP. Advancement data from the Louisiana State University AgCenter’s sugarcane breeding program were evaluated to determine our success in incorporating the new resistant germplasm into the progeny advancing through this program.

Statistical methods

Data derived from the advancements of clones for the 1991 to 2002 crossing series were classified into RSB and non-RSB derived crosses. A cross was designated RSB if it had at least one parent (male or female) from the RSB program. The total number of clones advanced from seedlings that survived winter (Stage I) was calculated for the Stage II (first-clonal stage), Stage III (second-clonal stage), Stage IV (variety yield trials/seed-increase stage) and Stage V (assignment of varieties planted in replicated variety trials).

The multinomial cumulative logit model of the logistic procedure of SAS (SAS Institute, 2007) was used to test if the advancement rates were different between the RSB and non-RSB derived populations. The analysis assumed that the stages of selection were ordered with proportional odds (Agresti, 2007). The cumulative logit model is also known as ordered or ordinal logit model (Allison, 2003). The statistical model used was,

\[
\text{Logit } [P(Y \leq j)] = \alpha_j + \beta x, \quad j = 1, 2, \ldots, J-1, \quad \text{Equation 1}
\]

where \(\alpha_j\) is the intercept of the \(j\)th stage and \(\beta\) is the coefficient describing the effect of \(x\) (RSB or non-RSB population) on the advancement rates. The number of seedlings advanced was used to determine the cumulative proportions that were in turn used to compute the odds ratios (Appendix 1). The model in Equation 1 and the SAS code in Appendix 1 were also used for simulating the effect of increasing the selection rate for the RSB population on the chance of increasing genotypes that reached the assignment stage.

Results

The number of seedlings derived from RSB resistant parents was less than 5% of the seedlings derived from non-RSB parents (Table 1). The trends in Table 1 were consistent across all the crossing series from 1991 to 2002 (data not shown). When the number of seedlings advanced was expressed as a percent of seedlings that survived the winter and plotted against stage of the breeding program (Figure 1), the % advancement of clones from RSB and non-RSB parents was similar across stages.

A statistical test using cumulative logit model (Appendix 1) showed non-significant difference (\(P > 0.05\)) in advancement rates between RSB and non-RSB families (Table 2). However, because of fewer seedlings derived from RSB crosses, very few genotypes were advanced to replicated variety trials from the RSB population; only seven from the 1991 to 2002 series. We therefore explored potential strategies for increasing advancements of genotypes from the RSB population.

Table 1—The number of seedlings or clones in Stages I, II, III, IV and V from the RSB and non-RSB derived populations, 1991–2002.

<table>
<thead>
<tr>
<th>Population</th>
<th>Stage I</th>
<th>Stage II</th>
<th>Stage III</th>
<th>Stage IV</th>
<th>Stage V</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSB</td>
<td>17661</td>
<td>1163</td>
<td>228</td>
<td>94</td>
<td>7</td>
</tr>
<tr>
<td>Non-RSB</td>
<td>376776</td>
<td>24661</td>
<td>5299</td>
<td>2162</td>
<td>300</td>
</tr>
</tbody>
</table>
A simulation study was done using the cumulative logit model (Equation 1) and the SAS code (Appendix 1) to determine the effect of increasing selection rates at the different stages of the breeding program. The sensitivity analysis was performed to determine the stages that would produce the greatest effect on the numbers of genotypes reaching Stage V.

Sensitivity analysis enables the variation in the output of a model to be apportioned to the different sources of the variability that occurs in the input variables (Helton et al., 2006).

The sensitivity analysis was evaluated by increasing the selection rates between the stages and identifying the stage that would result in the greatest and most significant increase in advancement rates. The selection rate from Stage I to Stage II was the most influential resulting in a significant increase in advancement of RSB derived genotypes (Figure 2).

Increasing advancement rates for Stage IV for the overall breeding population, for example, resulted in marginal increases of advancements to Stage V for genotypes from the RSB population alone. Table 2 and Figure 2 show the impact of increasing selection rates from Stage I to Stage II.

There was a marginal increase in the odds of advancing an RSB genotype compared to the odds of advancing non-RSB from Stage II to Stage III, Stage III to Stage IV, and Stage IV to Stage V.

The simulation study showed that increasing selection rates to 8% (Stage I to Stage II) resulted in a 20% (P < 0.01) increase in the odds of advancement to Stage V for genotypes from the RSB population.

A 13% selection rate (double the current selection rate) would almost double the odds of advancement to Stage V and the odds of advancement were tripled at 20% selection rate. The sensitivity analysis also showed that, by adjusting the selection rate at Stage I, the number of genotypes advanced at other stages would significantly (P < 0.05) increase (data not shown).
Table 2—The odds ratio of advancing clones from RSB vs non-RSB derived populations, 95% confidence limits and the Chi-Square tests for different selection rates, Stage I to Stage II.

<table>
<thead>
<tr>
<th>Selection rate (%)</th>
<th>Odds Ratio (RSB vs non-RSB)</th>
<th>Odds ratio 95% confidence limits</th>
<th>Wald Chi-Square</th>
<th>Probability &gt; Chi-Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.55†</td>
<td>0.98</td>
<td>0.93, 1.04</td>
<td>0.52</td>
<td>0.47</td>
</tr>
<tr>
<td>8</td>
<td>1.20</td>
<td>1.14, 1.26</td>
<td>51.21</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>10</td>
<td>1.50</td>
<td>1.43, 1.57</td>
<td>307.29</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>13</td>
<td>1.94</td>
<td>1.86, 2.02</td>
<td>1029.78</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>14</td>
<td>2.09</td>
<td>2.01, 2.17</td>
<td>1348.50</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>17</td>
<td>2.53</td>
<td>2.44, 2.63</td>
<td>2482.34</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>20</td>
<td>2.97</td>
<td>2.87, 3.07</td>
<td>3841.30</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

† Test of the difference in current selection rates between RSB and non-RSB families

Fig. 2—The odds ratio of assignment for RSB vs non-RSB clones (y-axis) plotted against assignment rates (%) (x-axis) for different selection rates, Stage I to Stage II.

Discussion

*Diatraea saccharalis* resistance in sugarcane is a highly heritable trait and, by careful selection of resistant parents, the population mean of progeny evaluated in the LSVP can be shifted to higher levels of resistance. For this strategy to be successful, however, a sufficient representation of these crosses must be planted in initial seedling populations and an appropriate selection rate must be practised. The selection stage that is targeted for increasing the selection rates from the crosses derived from parents resistant to the sugarcane borer is important.

Results from the sensitivity analysis showed that increasing selection rates from Stage I to Stage II would result in a significant increase in the number of genotypes assigned. Increasing the selection rates of the intermediate stages (without increasing selection rates at the seedling stage, Stage I) only resulted in marginal and non-significant increases in assignment rates. Furthermore,
increasing the advancement rates from Stage IV alone did not result in significant increases in the number of genotypes advanced to Stage V from RSB families.

The greatest variability in most trait values is in the non-selected seedling population (Stage I). Therefore, increasing selection rates at the seedling stage is expected to capture greater variability and would potentially include those transgressive segregants combining positive agronomic traits with sugarcane borer resistance.

After the seedling stage, further evaluation and selection eliminates those genotypes with poor agronomic performance from a larger pool of sugarcane borer resistant genotypes. Increasing selection rates at later stages did not significantly increase assignment rates because variability is less and many genotypes that combine both high yield potential and borer resistance would have been lost at the seedling selection. Selection in seedlings is inefficient (Cox and Stringer, 1998; Hogarth and Berding, 2006); therefore, higher selection rates from seedlings would provide more genotypes to screen for agronomic traits in later stages.

Consistent strategies are required for increasing the number of borer resistant genotypes that are assigned as well as incorporating borer resistance into the breeding germplasm. Two approaches can be used; selecting more seedlings in Stage I from the RSB parents or increasing the number of crosses made using RSB parents.

The first approach should ensure a greater number of advancements to Stage V, but selecting more seedlings from a smaller population may limit diversity and require the breeder to advance unacceptable clones. Alternatively, increasing the number of crosses made using RSB parentage would result in a larger population to select from and a corresponding increase of RSB genotypes advanced to Stage V at current selection rates. Increasing the number of crosses made with RSB parents would increase the gene pool to select for recombinants that are likely to combine both borer resistance and agronomic traits. The other advantage of increasing RSB parents is that genetic studies can also be carried out to investigate the ability to combine borer resistance and agronomic traits.

Such studies, if positive, would enhance the overall quality of the commercial gene pool, by incorporating an additional desirable trait. Increasing the number of RSB parents does not come without a price. Disadvantages of this approach would be the extra cost (land, labour, equipment, etc.) involved if crosses with these parents add to the number of seedlings evaluated in the program. Alternatively, the number of crosses could remain stable, with a higher percentage of RSB seedlings being planted in the general population. However, this would be done at the expense of traditional commercial breeding crosses.

While the primary objective of commercial breeding is to develop varieties, an additional objective is to improve the gene pool. When selecting from the RSB crosses, in addition to selecting for commercial varieties, we also identify genotypes that may have a small weakness, rendering it not acceptable for commercial production, yet still possessing most of the desired agronomic traits together with borer resistance. Selection of both sets of genotypes will have the positive effect of enhancing the commercial germplasm.

This approach will require evaluating genotype selections targeted to be parental material only, alongside those selected for their commercial potential. The benefits of the RSB program to the commercial program would be enhanced through this approach and thus improve the overall economics of the Louisiana industry.

REFERENCES


Appendix 1. Multinomial cumulative logit SAS code used for data analysis. 1 = RSB population, 0 = non-RSB population; 3, 4, 5, 6, 7 = Stage I, Stage II, Stage III, Stage IV, Stage V, respectively

```
Data one; Input T$ S Count @@; Datalines;
1 3 17661 1 4 1163 1 5 228 1 6 94 1 7 7
0 3 376776 0 4 24661 0 5 5299 0 6 2162 0 7 300;
Proc logistic; weight count; class T; model S=T; run;
```

AMÉLIORATION VARIÉTALE DE LA CANNE À SUCRE POUR LA GESTION DU FOREUR DE LA TIGE *DIATRAEA SACCHARALIS*: PROGRÈS ET PERSPECTIVES POUR LA LOUISIANE

Par

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MOTS CLÉS: Résistance aux Ravageurs, Stratégie d’Amélioration Variétale.

Résumé

Le foreur de la tige, *Diatraea saccharalis* (F.), est un ravageur important de la canne à sucre en Louisiane. L’exploitation des variétés résistantes est un élément du programme de lutte intégrée pratiquée en Louisiane pour la gestion de ce ravageur. Toutefois, l’homologation des variétés résistante a été intermittente. En 1986, les chercheurs de l’USDA, l’Agricultural Research Service (ARS) et le LSU Agricultural Center – les deux programmes d’amélioration variétale en Louisiane – ont initié un effort commun pour augmenter la résistance au foreur de la tige sans encombrer le programme variétal de la Louisiane avec un caractère additionnel en sélection. Selon cette approche, les clones avec des niveaux élevés de résistance au foreur de la tige (PSR) développés par l’USDA, ARS à Houma par l’intermédiaire d’un programme de sélection récurrente ont été utilisés comme parents dans le programme d’hybridation. Des données de sélection du programme d’amélioration de la canne à sucre du Louisiana State University AgCenter’s ont été évaluées pour déterminer les chances de succès en incorporant le nouveau germoplasme résistant aux progénitures sélectionnées à travers ce programme. Un test statistique, utilisant le modèle cumulatif de logit, a démontré une différence non-significative (P > 0.05) dans les taux d’avancement des clones entre les familles PSR et non-PSR. Cependant, en raison d’un nombre réduit de descendants découlant des croisements avec au moins un parent PSR, très peu de clones de la population du PSR ont été alloués des assignations permanentes au statut de variété; seulement sept dans la série de 1991 à 2002. Une étude de simulation a été entreprise pour déterminer l’effet d’augmenter les taux de
sélection sur le recouvrement des clones du PSR à différents stades du programme d’amélioration variétale. Le modèle cumulatif de logit a démontré qu’une augmentation du taux de sélection du Stade I au Stade II pourrait engendrer une augmentation significative des clones du PSR assignés à la désignation de variété. À partir de cette étude, il a été proposé que le nombre de croisements résistants soit augmenté et le taux de sélection des croisements du PSR au Stade I soit doublé à 13%.

MEJORAMIENTO GENÉTICO DE CAÑA DE AZÚCAR PARA EL MANEJO DEL BARREBADOR DEL TALLO DIATRAEA SACCHARALIS: PROGRESOS Y PROYECCIONES PARA LUISIANA

Por

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PALABRAS CLAVE: Resistencia A Insectos, Estrategias de Fitomejoramiento.

Resumen

EL BARRENADOR del tallo, Diatraea saccharalis (F.), es un insecto plaga de la caña de azúcar importante en Luisiana. El uso de variedades resistentes es un componente del Programa de Manejo Integrado de Plagas practicado en Luisiana para este insecto; sin embargo, la entrega de variedades resistentes no ha sido constante. En 1986, investigadores del USDA, Servicio de Investigación Agrícola (ARS) y el Centro de Agricultura de LSU – los dos programas de Luisiana – iniciaron esfuerzos para incrementar la resistencia al barrenador del tallo como un carácter adicional, sin modificar el programa de variedades de Luisiana (LSVP). Con esta proyección, clones con niveles altos de resistencia al barrenador del tallo están siendo desarrollados en USDA, ARS en Houma mediante selección recurrente para resistencia al barrenador (RSB) y estos clones resistentes son usados como parentales para los cruzamientos. Datos avanzados del programa de mejoramiento de caña de Louisiana State University AgCenter’s fueron analizados para determinar el éxito de la incorporación del nuevo germoplasma resistente dentro de las progenies avanzadas de todo el programa de selección. El test estadístico usando el modelo logit no mostró diferencias significativas (P > 0.05) entre las evaluaciones de clones avanzados entre familias de las RSB y no-RSB. Sin embargo, debido a que pocas plántulas obtenidas de cruzas con al menos una RSB estuvo presente, muy pocos clones fueron asignados códigos varietales desde las poblaciones de RSB, con únicamente siete de las series 1991 a 2002. Se realizó un estudio de simulación para determinar el efecto del incremento de la tasa de selección para la recuperación de clones de las RSB de diferentes estados del programa de cruas. El modelo logit mostró que incrementando la tasa de selección de Estado I a Estado II incrementará significativamente los clones con códigos varietales provenientes del RSB. Con este estudio proponemos que el número de cruzas resistentes se incrementen y la tasa de selección de las cruzas de RSB en Estado I sea duplicado a 13%.
GGE BIPLOT ANALYSIS USED TO EVALUATE CANE YIELD OF SUGARCANE 
(Saccharum spp.) CULTIVARS ACROSS SITES AND CROP CYCLES

By

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KEYWORDS: GGE Biplot, Genotype-by-Environment (GE) Interaction, Principal Components (PC).

Abstract

MULTI-ENVIRONMENT yield trials (MET) are a series of experiments in which a set of genotypes (G) are evaluated in multiple environments (E). The presence of genotype × environment (GE) interaction observed in MET complicates the selection and/or recommendation of cultivars. Several statistical methodologies have been developed for the analysis of GE interaction. GGE biplot of the SREG model is a recent methodology based on a graph formed with the first two principal components (PC1 and PC2). GGE represents the G main effect plus the GE interaction effects. Thus, GGE biplot provides an adequate graphical tool for visual analysis of MET data. The objectives of this research were to evaluate sugarcane cultivar responses across environments in order to identify high-yielding cultivars with broad or specific adaptation by applying the GGE biplot analysis. Fourteen sugarcane cultivars were evaluated at three sites in the plant, first and second ratoon crops across the middle land zone of the sugarcane growing area of Guatemala, forming nine environments (three sites × three crop cycles). Data on tonnes of cane per hectare (TCH) were recorded. The first two principal components (PC1 and PC2) were highly significant (P<0.01) and explained 73% of the GGE. GGE biplot analysis allowed selection of the sugarcane cultivar PR75-2002 as second on average cane yield and had broad adaptation (stable). Two groups of environments (mega-environments) were defined; the first had seven environments and the second one had two environments. The winning cultivars with the highest cane yield were CG00-120 and CG00-092 for each of those groups (specific adaptation), respectively. The G main effect and GE interaction can be exploited by selection of highest cane yield cultivars for each mega-environment.

Introduction

Multi-environment yield trials (MET) are a series of experiments in which a set of genotypes (G) is evaluated in multiple environments (E), usually considered as being the environments as a combination of sites and years. These trials are important because the presence of genotype × environment interaction (GE) complicates the selection and/or recommendation of cultivars. In order to illustrate this fact, if there is no GE interaction, a single test environment would be sufficient for cultivar testing. Thus, the understanding of the GE interaction observed in MET is very useful in breeding programs in order to identify high-yielding cultivars with broad or specific adaptation (Annicchiarico, 1997; Gauch, 1992; Smith et al., 2001; Yan and Hunt, 2002).

The GE interaction with special interest for breeding programs is that which creates a change in ranking of the cultivars from one environment to another (crossover-interaction). This means that the best cultivar in one particular environment might not be the best in another environment. Several statistical methodologies have been developed for the analysis of GE
interaction (Kang, 2002). Sites (i.e., environment) Regression (SREG) is a linear (additive component) – bilinear (multiplicative component) model which in the bilinear terms absorbs the main effects of G plus the GE interaction (Crossa and Cornelius, 2002; Crossa et al., 2002). Breeders have used the recent methodology GGE biplot from the SREG model to analyse MET data (Burgueño et al., 2009; Yan et al., 2000).

The GGE represents the main effect of genotype plus the genotype by environment interaction (G+GE). GGE biplot of SREG model is based on principal components analysis, and a graph is formed with the scores of the genotypes and the environments of the first principal component (PC1 scores) against their respective scores for the second principal component (PC2 scores). GGE biplot displays the two sources of variation G and GE, and provides an adequate graphical tool for cultivar evaluation (yield and stability), mega-environment analysis (such as ‘which-won-where’ pattern), test-environment evaluation (discriminating among genotypes and representativeness of the mega-environments) and others (Burgueño et al., 2009; Crossa et al., 2002; Ding et al., 2009; Yan et al., 2007).

The present MET study was conducted with 14 sugarcane (Saccharum spp.) cultivars, which were evaluated across nine environments (combinations of three sites and three crop cycles) in Guatemala. The objectives of this research were to evaluate sugarcane cultivar responses across environments in order to identify high-yielding cultivars with broad or specific adaptation by applying the GGE biplot analysis.

Materials and methods

This study was part of a series of multi-environment yield trials of the Sugarcane Breeding and Development Program of CENGICAÑA where 14 sugarcane cultivars were evaluated in nine environments of the sugarcane production area in the middle land zone of Guatemala (Table 2). The nine environments refer to sites × crop cycle (crop-year) combinations. There were three sites: San Bonifacio (280 masl), Margaritas (116 masl) and Tululá (220 masl); and three crop cycles: plant cane (harvest season, 2004–05), first (2005–06) and second ratoon crops (2006–07). Of the 14 cultivars tested, 12 are from CENGICAÑA Guatemala (CG and CGSP) and two testers, one cultivar from Canal Point (CP) and one from Puerto Rico (PR). The field experimental design used for each trial was a Randomised Complete Block with four replications and with experimental units of 75 m². Data on tonnes of cane per hectare (TCH) were recorded.

The GGE biplot from the SREG model was constructed according to the manual and SAS program available at the web page of CIMMYT in Biometrics and Statistic Unit (BSU) or at http://www.cimmyt.org/english/wps/biometrics/. Following Burgueño et al. (2009), Yan et al. (2001) and Yan and Hunt (2002), a brief description and interpretation of the GGE biplot is presented below:

**PC1 (as x-axis) and PC2 (as y-axis)**

The biplot GGE is formed with PC1 scores on the abscissa and PC2 scores on the ordinate for each cultivar and each environment. PC1 represents the average yield of cultivars if the genotype PC1 scores are highly correlated with the genotype main effects; while PC2 is related to the GE interaction.

**Cultivar and environment vectors**

The cultivars and environments can be visualised as vectors from the origin of axis (0, 0) to the end points determined by their scores. The environment scores have the same orientation to the right (same sign). Cultivars that are far from the origin have positive responses with environments that are far from the origin but in the same direction. Ideal cultivars: large PC1 scores (higher mean yield) and PC2 scores near to zero (more stable). Ideal test environments: Large PC1 scores (high capacity to discriminate among cultivars) and PC2 scores near to zero (‘more representative of an average environment’).
External polygon and biplot sectors

External polygon is formed with the cultivars located farthest from the biplot origin (0, 0). These cultivars are part of the corners of the polygon (cultivar markers) and are connected with straight lines. Cultivar markers are the ones with the highest response and they could be the best or the worst in some or all of the environments. Perpendicular segmented lines to each side of the polygon are drawn to divide the biplot in different sectors of cultivars and environments. The cultivar located in the corner of one sector is the winner cultivar with the highest yield in the environment or environments of this sector.

Results and discussion

The combined analysis of variance (Table 1) showed differences statistically significant (P<0.01) among environments, genotypes and GE interaction. Based on the relative contribution of sum of squares, the environmental effect had the highest contribution, followed by genotypes and lastly the GE interaction. The first two principal components (PC1 and PC2) were highly significant (P<0.01) and explained 73% of the GGE (PC1=61% and PC2= 12%). Cultivar PC1 scores and the cultivar yield means (Table 2) were highly correlated (r=0.99), which was expected, since PC1 explained most of the GGE variation (61%). These results are consistent with those of Yan et al. (2001), who indicated that a poor correlation occurs when GGE is explained by PC1 and PC2 in similar contribution (complex GE interaction).

Table 1—Additive main effects and multiplicative interactions analysis of variance on cane yield (t/ha) of the genotypes across environments.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Degrees of freedom</th>
<th>Sum of squares</th>
<th>Mean squares</th>
<th>F</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environment (E)</td>
<td>8</td>
<td>317846</td>
<td>39731</td>
<td>119</td>
<td>0.000</td>
</tr>
<tr>
<td>Genotypes (G)</td>
<td>13</td>
<td>77260</td>
<td>5943</td>
<td>18</td>
<td>0.000</td>
</tr>
<tr>
<td>GE</td>
<td>104</td>
<td>69722</td>
<td>670</td>
<td>2</td>
<td>0.000</td>
</tr>
<tr>
<td>GGE</td>
<td></td>
<td>146982</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC1</td>
<td>20</td>
<td>90258</td>
<td>4513</td>
<td>14</td>
<td>0.000</td>
</tr>
<tr>
<td>PC2</td>
<td>18</td>
<td>17733</td>
<td>985</td>
<td>3</td>
<td>0.000</td>
</tr>
<tr>
<td>Error</td>
<td>351</td>
<td>116865</td>
<td>333</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

According to the GGE biplot (Figure 1), no cultivar was identified which had high average yield (large PC1 score) and stability in performance (PC2 score near to zero). However the cultivar 13 (PR75-2002) was close to ideal because it had the second highest average cane yield and a PC2 score near to zero (–0.1).

Regarding test environments, S2Y1 (Margartias-plant cane) and S2Y2 (Margartias-first ratoon) environments were identified as near to an ideal environment since they presented large PC1 score and PC2 score near to zero (Table 2 and Figure 1). This indicates that this site (Margartias) would be useful for selecting cultivars which have a high correlation across all environments.

The S3Y1, S3Y2, S3Y3 and S1Y1 environments were near to the biplot origin (0, 0) with short vectors; thus these environments were not useful for cultivar discrimination. The S2Y3 environment had the largest vector with large PC1 and PC2 scores of 5.9 and –3.6 respectively (Table 2).

This environment adequately discriminated the cultivar 5 (CG00-120) with large vector in the same direction. The same interpretation can be given to environments S1Y2 and S1Y3 with the cultivar 8 (CG00-092). These results suggest that the GE interaction in sugarcane increases as the years (crop cycles) also increase.
Table 2—Mean yield of cane (t/ha) of 14 sugarcane cultivars in nine environments and PCA1 and PCA2 scores for each cultivar and environment.

<table>
<thead>
<tr>
<th>Code</th>
<th>Cultivars</th>
<th>Environments †</th>
<th>Grand Mean</th>
<th>PC1 ‡</th>
<th>PC2 ‡</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>S1Y1</td>
<td>S1Y2</td>
<td>S1Y3</td>
<td>S2Y1</td>
</tr>
<tr>
<td>1</td>
<td>CGSP98-08</td>
<td>161</td>
<td>131</td>
<td>129</td>
<td>177</td>
</tr>
<tr>
<td>2</td>
<td>CG00-032</td>
<td>121</td>
<td>124</td>
<td>127</td>
<td>148</td>
</tr>
<tr>
<td>3</td>
<td>CGSP98-05</td>
<td>136</td>
<td>122</td>
<td>116</td>
<td>176</td>
</tr>
<tr>
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<td>CGSP98-16</td>
<td>140</td>
<td>117</td>
<td>104</td>
<td>192</td>
</tr>
<tr>
<td>5</td>
<td>CG00-120</td>
<td>159</td>
<td>150</td>
<td>146</td>
<td>212</td>
</tr>
<tr>
<td>6</td>
<td>CG00-129</td>
<td>131</td>
<td>138</td>
<td>133</td>
<td>168</td>
</tr>
<tr>
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<td>CG00-001</td>
<td>158</td>
<td>106</td>
<td>107</td>
<td>176</td>
</tr>
<tr>
<td>8</td>
<td>CG00-092</td>
<td>161</td>
<td>169</td>
<td>162</td>
<td>200</td>
</tr>
<tr>
<td>9</td>
<td>CG99-045</td>
<td>145</td>
<td>114</td>
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<tr>
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<td>11</td>
<td>CG00-044</td>
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<td>146</td>
<td>129</td>
<td>192</td>
</tr>
<tr>
<td>12</td>
<td>CG99-014</td>
<td>151</td>
<td>150</td>
<td>142</td>
<td>204</td>
</tr>
<tr>
<td>13</td>
<td>PR75-2002</td>
<td>174</td>
<td>154</td>
<td>132</td>
<td>231</td>
</tr>
<tr>
<td>14</td>
<td>CP72-2086</td>
<td>140</td>
<td>115</td>
<td>115</td>
<td>175</td>
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<td></td>
<td>Grand Mean</td>
<td>144</td>
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<tr>
<td></td>
<td>PC1 ‡</td>
<td>2.4</td>
<td>4.3</td>
<td>3.1</td>
<td>5.7</td>
</tr>
<tr>
<td></td>
<td>PC2 ‡</td>
<td>−2.1</td>
<td>4.9</td>
<td>4.6</td>
<td>−0.3</td>
</tr>
</tbody>
</table>

† Environments are a combination of sites and crop cycles. Sites: S1=San Bonifacio, S2=Margaritas and S3=Tululá. Crop cycles: Y1=Year 1 (Plant Cane), Y2=Year 2 (First Ratoon) and Y3=Year 3 (Second Ratoon).
‡ PCA1 and PCA2 = First and second principal component respectively.

The site 2 (Margaritas) is characterised by adequate soil and weather conditions compared with site 3 (Tululá); therefore, the environments that include the site 2 had high capacity to discriminate among cultivars, as indicated by data in Table 2 and represented graphically in the GGE biplot (Figure 1).
The ‘which-won-where’ patterns were determined by the polygon (Figure 1). The corners of the polygon were formed with five cultivars from which cultivars 5 (CG00-120) and 8 (CG00-092) showed the best response in TCH. The poorest cultivars were 4 (CG00-120), 7 (CG00-092) and 2 (CG00-032) because they are in an opposite direction to the environments. According to the GGE biplot, two sectors (mega-environments) were defined; the first sector made up by seven environments (Margaritas and Tululá with their three crops cycle plus San Bonifacio with its first ratoon); and the second one by two environments (San Bonifacio with its second and third crops). The winning cultivars with the highest yield were 5 (CG00-120) and 8 (CG00-092) for each of the sectors, respectively.

Conclusions

GGE biplot analysis allowed selection of the sugarcane cultivar PR75-2002 as second for average cane yield and with broad adaptation (stable).

Two groups of environments (mega-environments) were defined; the first made up of seven environments and the second one of two environments. The winning cultivars with the highest cane yield were CG00-120 and CG00-092 for each of the groups (specific adaptation) respectively.

The G main effect and GE interaction can be exploited by selection of highest cane yield cultivars for each mega-environment.

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L’UTILISATION DE L’ANALYSE BIPILOT GGE POUR L’ÉVALUATION DU RENDEMENT DES CULTIVARS DE LA CANNE À SUCRE (*Saccharum* spp.) À TRAVERS LES SITES ET LES CYCLES DE CULTURE

Par

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MOTS CLÉS: Biplot GGE, Interaction Génotype × Environnement (GE), Composantes Principales (PC).

Résumé

Les essais multi-locaux (MET) constituent une série d’essais variétaux où une group de génotypes (G) sont évalués dans divers environnements (E). La présence de l’interaction génotype x environnement (GE) complique la sélection et/ou les recommandations des cultivars. Plusieurs méthodes statistiques ont été développées pour l’analyse de l’interaction GE. Le biplot GGE découlant du modèle SREG est une méthodologie récente basée sur la courbe formée des deux composantes principales (PC1 et PC2). Le GGE représente l’effet principal G plus les effets de l’interaction GE. Donc, le biplot GGE fourni un outil graphique adéquat pour une analyse visuelle des données MET. Les objectifs de cette recherche étaient d’évaluer le comportement des cultivars à travers les environnements afin d’identifier les cultivars à forts rendements à adaptations larges ou spécifiques en utilisant l’analyse biplot GGE. Quatorze cultivars de canne à sucre ont été évaluées sur trois sites en vierge, première et deuxième repousses dans la zone centrale où la canne est cultivée au Guatemala, totalisant neuf environnements (trois sites x trois récoltes). Le rendement en tonne de canne à l’hectare (TCH) étaient recueilli. Les deux premières composantes principales (PC1 et PC2) étaient hautement significatives (P<0.01) et contribuaient à hauteur de 73% de l’interaction GGE. L’analyse biplot GGE a permis la sélection du cultivar PR75-2002 en deuxième position pour le rendement en canne avec une large aire d’adaptation large (stable). Deux groupes d’environnements (mega-environnements) étaient définis; le premier avec sept environnements et le second avec deux environnements. Les cultivars gagnants avec les rendements les plus élevés étaient CG00-120 et CG00-092 pour chacun de ces deux groupes (adaptation large et spécifique) respectivement. L’effet principal G et l’interaction GE peuvent être exploités en sélectionnant les cultivars avec les plus forts rendements pour chacun de ces mega-environnements.
ANALISIS GGA BIPLOT UTILIZADO PARA EVALUAR EL RENDIMIENTO DE CAÑA EN CULTIVARES DE CAÑA DE AZÚCAR (Saccharum spp.) A TRAVES DE SITIOS Y CICLOS DEL CULTIVO

Por

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PALABRAS CLAVE: GGA biplot, Interacción Genotipo × Ambiente (GA), Componentes Principales (CP).

Resumen

ENSAYOS de rendimiento en multi-ambientes (EMA) son una serie de experimentos en los cuales un grupo de genotipos (G) son evaluados en diferentes ambientes (A). La presencia de la interacción genotipo × ambiente (GA) observada en EMA complica la selección y / o recomendación de cultivares. Varias metodologías estadísticas se han desarrollado para el análisis de la interacción GA. GGA biplot del modelo de Regresión de sitios (SREG) es una metodología reciente basada en una gráfica formada con los dos primeros componentes principales (CP1 y CP2). GGA representa el efecto principal de G más los efectos de la interacción GA. Así, GGA biplot proporciona una herramienta gráfica adecuada para el análisis visual de datos provenientes de los EMAs. Los objetivos de esta investigación fueron evaluar las respuestas de cultivares de caña de azúcar a través de ambientes con el fin de identificar cultivares de alto rendimiento con una adaptación amplia y específica mediante la aplicación análisis GGA biplot. Catórice cultivares de caña de azúcar fueron evaluados en tres sitios en plantía, primera y segunda soca a través de la zona media de producción de caña de azúcar de Guatemala, formando nueve ambientes (tres localidades × tres ciclos del cultivo). Se registraron datos de toneladas de caña por hectárea (TCH). Los dos primeros componentes principales (CP1 y CP2) fueron altamente significativos (P <0.01) y explicaron el 73 % del GGA. GGA biplot permitió seleccionar el cultivar PR75-2002 como segundo lugar en el promedio en rendimiento de caña con adaptación amplia (estable). Dos grupos de ambiente (mega-ambientes) fueron definidos, el primero compuesto por siete ambientes y el segundo por dos ambientes. Los cultivares ganadores con mayor rendimiento de caña fueron: CG00-120 y CG00-092 para cada uno de los grupos, respectivamente (adaptación específica). El efecto principal G y los efectos de la interacción GA pueden ser efectivamente explotadas mediante la selección de cultivares de mayor rendimiento para cada mega-ambiente.
TOLERANCE OF SUGARCANE PARENTS TO HERBICIDES AND ITS TRANSMISSION IN PROGENY

By

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KEYWORDS: Herbicide Applications, Inheritance of Herbicide Tolerance, Post-Emergence.

Abstract

SUGARCANE varieties with one or both parents in common have been observed to show a similar tolerance level to the tank-mix of diuron and Actril-DS®. This study was initiated to evaluate parent varieties frequently used in the breeding program of the Institute, for transmission of their tolerance to herbicide in crosses. Sixty parents established in pots and later transplanted in replicated field trials were evaluated for their tolerance to the test herbicide tank-mix. Crosses were made with some selected parents with known tolerance and 15 families, comprising 40 seedlings each, were subsequently evaluated for their response to the same tank-mix. Parents differed significantly in their tolerance to herbicide and were classified as: tolerant (T) 10%; slightly susceptible (SS) 34%; moderately susceptible (MS) 25%; susceptible (S) 25%; highly susceptible (HS) 7%. The phenotypic correlation between the degree of tolerance to the herbicide tank-mix evaluated in pots and in the field was moderately high, indicating that assessment of response of genotypes in pots can provide a useful indication of expression of tolerance at field level. The families also differed significantly in their tolerance to herbicide. Generally, crosses between T/SS × MS parents produced about 40% and 46% of progenies in the T/SS and MS classes, respectively. Conversely, S × HS crosses produced a very high proportion (75%) of progenies in the S/HS. The degree of susceptibility to herbicide increases with the degree of susceptibility of the parental combination. A clear-cut segregation towards either T/SS or S/HS groups was not evident that could indicate the action of a major gene. Partitioning of variance indicated a high component of additive genetic variance, high narrow-sense heritability, and the possibility of breeding for the character through a judicious choice of parent varieties.

Introduction

Chemical weed control is a commonly used practice in sustainable sugarcane production. Herbicides are tested individually, in mixed formulation or in tank-mixes to evaluate their efficacy in weed control, the cost of application and the level of phytotoxicity to the crop. More than 100 weed species consisting of broad-leaved weeds, grasses and sedges are common in sugarcane fields in Mauritius; some sixty of the most commonly found ones have been described by Mc Intyre (1991). Tank mixing of two or more herbicides to achieve a broader spectrum of control is a common practice in sugarcane production (Seeruttun, 2007).

Diuron has been widely used as a pre-emergence treatment in sugarcane; it is also tank-mixed with Actril DS® (ioxynil + 2,4-D ester) in post-emergence of weeds. Diuron, a photosynthetic II inhibitor, is a substituted urea herbicide used to control a wide variety of annual and perennial broad-leaved weeds and grasses. Actril DS® is a selective herbicide, a member of the Nitrile and Phenoxy group with ethyl hexyl ester (2,4-D) and ioxynil as active ingredients for the control of broadleaved weeds and vines in sugarcane.
Commercial sugarcane varieties have frequently been tested for their tolerance to post-emergence herbicides in Mauritius (MSIRI 1980, 1990, 1994, 1995) but information on the genetic transmission of herbicide tolerance in sugarcane has not been widely reported. Concurrently, herbicide resistance transformation technology has been widely successful in conferring herbicide tolerance in sugarcane (Autrey et al. 2001/2002; Leibbrandt and Snyman 2001; Enriquez et al., 2001; Butterfield and Ulian, 2006; Snyman et al., 2001). However, herbicide-resistant (HR) transgenic crops can present several risks through escape and proliferation of the transgenic plants as weedy volunteers, hybridisation with and transgene infiltration into related or wild species, and changes in population dynamics of unrelated species and the development of herbicide-resistant biotypes (Warwick et al., 1999; Yong Woong and Do-Soon, 2001; Warwick and Francis, 2005). Breeding for herbicide tolerance constitutes a safe avenue to guard against risks associated with transgenic technology.

Several varieties, released in Mauritius, and having one or both parents in common have been observed to show similar tolerance level to the tank-mix of diuron and Actril-DS®. This study was initiated to evaluate parent varieties, frequently used in the breeding program of the Institute with a view to study the variation for herbicide tolerance and also to obtain information on the transmission of tolerance to herbicide in crosses. It aims to assess the possibility of breeding for herbicide tolerance.

Materials and methods

A total of 60 parent varieties produced locally and imported from diverse sources that are frequently used in the MSIRI breeding program were chosen to evaluate their degree of tolerance/sensitivity to the herbicide tank-mix diuron + Actril DS® at 2.5 + 1.3 kg a.i./a.e./ha using the precision sprayer Micron AutoDos. Five (replicates) of one-eyed cuttings of each variety were planted in plastic pots of size 15 × 15 cm on 20 September 2005 at Réduit Experimental Station (rainfall 1400 mm, elevation 300 m). The five replicates of each variety were grouped together in a single row on concrete flooring in the nurseries and allowed to grow in open sunlight. About 12 weeks after potting, the herbicide tank-mix was sprayed on each plant developed from the pots on 15 December 2005. Sensitivity to the tank-mix of herbicide was visually evaluated on the individual plants two weeks after spraying (WAS) based on a five-point scale as follows: 5-tolerant (T) - no sign of leaf damage, 4-slightly susceptible (SS) – slight chlorosis, 3-moderately susceptible (MS) – moderate chlorosis, 2-susceptible (S) – severe scorching and chlorosis and 1-highly susceptible (HS) – very severe scorching and cane growth stunted.

In April 2006, the pots were transplanted at Union Park Experimental Station (rainfall 3100 mm, elevation 375 m) in 1-m rows with two pots per row spaced at 0.50 m within rows and 1.5 m between rows with two replicates in a completely randomised block design. The plants were allowed to develop freely and they were stubble-shaved seventeen months after transplanting in September 2007. The ratoon plants were sprayed with the same herbicide tank-mix at the same dosage four weeks later in October and the degree of sensitivity to the herbicide was assessed visually four weeks later in November.

A number of crosses were attempted between May and July 2007 between parents varying in herbicide sensitivity based on the evaluation made in pots earlier in 2005 and also on knowledge acquired on the reactivity of the commercial varieties that were included in the trial. Fifteen families, from the 2007 crossing season and past years that have produced enough seedlings were chosen to study the transmission of herbicide tolerance. The trial was laid down with 40 seedlings of each family grown in plastic pots (15 cm × 15 cm) in a randomised complete block design with two replicates of 20 seedlings per family. The same herbicide tank-mix was applied on each seedling at the age of 12 weeks after potting using the precision sprayer Micron AutoDos. Visual assessment of the tolerance level of each seedling progeny was done four WAS as per the rating described above.
Statistical analyses

Means and standard errors (SE) were calculated for each parent variety evaluated in pots and in the field as well as for each family evaluated in pots. Phenotypic correlation coefficient for sensitivity levels of parent varieties recorded in pots and in field was calculated. Frequency distributions for progeny within sensitivity classes were derived for each family. Partitioning of variances was performed between and within families and the estimates of the variance components were derived as per the methodology of Kearsey and Pooni (1996) for bi-parental families.

From expectation of mean squares: \( \sigma^2_W = \frac{1}{2} V_A + V_E \) and \( \sigma^2_B = \frac{1}{2} V_A \), assuming negligible dominance effects; where \( \sigma^2_W \) = expected average variance within full-sib families and \( \sigma^2_B \) = expected variance of true family means, \( V_A \) = additive genetic variance and \( V_E \) = environmental variance. Narrow-sense heritability was calculated as \( h^2 = \frac{V_A}{V_A+V_E} \).

The number of progeny per family, \( r \), was corrected for unequal number of seedlings as a result of differential mortality (Sokal and Rolf, 1981). The standard error of the estimate of narrow-sense heritability was derived from twice the square root of the variance of the intra-class correlation based on the methodology of Fisher (1954) for the estimation of standard error of repeatability.

Results and discussions

Sensitivity levels of parent varieties

The mean sensitivity levels of parent varieties and their assignment to tolerance classes observed in pots and in the field are presented in Table 1. The parent clones differed significantly in their tolerance to the herbicide tank-mix. The frequency distribution of varieties within tolerance classes measured in pots was as follows: tolerant (T) - 10%; slightly susceptible (SS) - 34%; moderately susceptible (MS) - 25%; susceptible (S) - 25%; highly susceptible (HS) - 7%. This distribution indicates a wide variation in the tolerance/sensitivity levels of the parental pool with as high as 32% of the parents with low tolerance level if S and HS classes are grouped together.

There was a fairly good correlation in the reaction of the clones when measured in pots and their relative rating measured in field \((r=0.60**, p=0.01)\) although, for many of the clones, the rating was not strictly the same.

If tolerant and slightly susceptibility clones were grouped together in the tolerant class based on the reaction observed in pots, 18 out of 27 clones (67%) would have been classified in the tolerant class in the field and the rest assigned to the MS class.

From a total of 15 clones classified as MS in pots, an equal percentage of clones 67% (10) would have had the same rating in field. The highest discrepancy between the sensitivity of the clones measured in pots and in the field was observed for the S and HS classes. When these two classes are grouped together as a susceptible group measured in pots, only 33% of clones would have an equivalent rating at field level, 44% would be rated MS and 22% rated as SS such that the MS group is inflated.

It appears that the clones in the field, which were in a ratoon crop with an already well developed rooting system showed a lower sensitivity to herbicide toxicity. None of the clones rated as T/SS in pots would have acquired S/HS rating in the field and few (3) clones with S rating in pots had an SS rating in field. The measurement of herbicide tolerance levels in pots by the precision sprayer can constitute a quick and economic means for assessing the relative sensitivity of varieties to herbicides.

Sensitivity levels of progeny

Most of the crosses used in the progeny evaluation were between parents with determined herbicide tolerance, released for commercial cultivation in Mauritius. The assignment of the sensitivity level for these clones was predominantly based from current experience of their reactivity in commercial fields as well as reactivity shown in the present evaluation.
Table 1—Mean sensitivity levels (and standard error) of parent varieties to the tank-mix of herbicides observed in pots and in the field and their assignment to tolerance/sensitivity classes.

<table>
<thead>
<tr>
<th>Variety</th>
<th>Mean (pots)</th>
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<th>Tolerance class*</th>
<th>Mean (field)</th>
<th>se</th>
<th>Tolerance class*</th>
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<td>CP 44101</td>
<td>1.8</td>
<td>0</td>
<td>S</td>
<td>3.5</td>
<td>0.5</td>
<td>MS</td>
</tr>
<tr>
<td>M 202/46</td>
<td>1.8</td>
<td>0.37</td>
<td>S</td>
<td>4</td>
<td>0</td>
<td>SS</td>
</tr>
<tr>
<td>RB 739953</td>
<td>1.8</td>
<td>0.2</td>
<td>S</td>
<td>3.5</td>
<td>0.5</td>
<td>MS</td>
</tr>
<tr>
<td>CP 701133</td>
<td>1.7</td>
<td>0.2</td>
<td>S</td>
<td>2.5</td>
<td>0.5</td>
<td>S</td>
</tr>
<tr>
<td>M 1682/70</td>
<td>1.7</td>
<td>0.33</td>
<td>S</td>
<td>3.5</td>
<td>0.5</td>
<td>MS</td>
</tr>
<tr>
<td>NA 6390</td>
<td>1.6</td>
<td>0.33</td>
<td>S</td>
<td>2</td>
<td>0</td>
<td>S</td>
</tr>
<tr>
<td>R 570</td>
<td>2.0</td>
<td>0.24</td>
<td>S</td>
<td>2</td>
<td>0</td>
<td>HS</td>
</tr>
<tr>
<td>M 555/60</td>
<td>1.6</td>
<td>0</td>
<td>HS</td>
<td>2</td>
<td>0</td>
<td>HS</td>
</tr>
<tr>
<td>TRITON</td>
<td>1.4</td>
<td>0.24</td>
<td>HS</td>
<td>3</td>
<td>1</td>
<td>S</td>
</tr>
<tr>
<td>F 77790</td>
<td>1.3</td>
<td>0.24</td>
<td>HS</td>
<td>3</td>
<td>0</td>
<td>MS</td>
</tr>
<tr>
<td>M 1246/64</td>
<td>1.3</td>
<td>0.33</td>
<td>HS</td>
<td>3</td>
<td>0</td>
<td>MS</td>
</tr>
</tbody>
</table>

*T-tolerant, SS-slightly susceptible, MS-moderately susceptible, S-susceptible, HS-highly susceptible
Progeny means for tolerance level, standard error (SE) and mid-parent values for the different categories of crosses measured in pots pooled over replicates are shown in Table 2. In general, irrespective of the tolerance level of the male parent, families with a tolerant or a slightly susceptible female parent had higher mean values for tolerance except cross 265/07 which showed high susceptibility to herbicide. Conversely, families with a MS or S female parent had slightly lower tolerance level (value) except for one cross, 1197/03, which displayed moderate tolerance level.

Table 2—Family mean, standard error and mid-parent value for tolerance level to herbicide mix measured in pots.

<table>
<thead>
<tr>
<th>Family reference</th>
<th>Female parent</th>
<th>Male parent</th>
<th>Tolerance category*</th>
<th>No observed</th>
<th>Mid-parent**</th>
<th>Mean progeny</th>
<th>se</th>
</tr>
</thead>
<tbody>
<tr>
<td>1577/06</td>
<td>M 1400/86</td>
<td>M 2343/77</td>
<td>T × MS</td>
<td>39</td>
<td>3.8</td>
<td>3.1</td>
<td>0.11</td>
</tr>
<tr>
<td>1217/03</td>
<td>M 1176/77</td>
<td>M 1246/84</td>
<td>T × MS</td>
<td>40</td>
<td>3.05</td>
<td>3.6</td>
<td>0.09</td>
</tr>
<tr>
<td>1287/03</td>
<td>M 1176/77</td>
<td>R 570</td>
<td>T × HS</td>
<td>40</td>
<td>3.4</td>
<td>3.2</td>
<td>0.13</td>
</tr>
<tr>
<td>1304/03</td>
<td>M 1400/86</td>
<td>R 570</td>
<td>T × HS</td>
<td>39</td>
<td>3.2</td>
<td>2.5</td>
<td>0.16</td>
</tr>
<tr>
<td>1225/03</td>
<td>R 575</td>
<td>M 1246/84</td>
<td>SS × MS</td>
<td>39</td>
<td>3.05</td>
<td>2.8</td>
<td>0.11</td>
</tr>
<tr>
<td>1574/06</td>
<td>M 744/70</td>
<td>M 2343/77</td>
<td>SS × MS</td>
<td>36</td>
<td>3.5</td>
<td>3.8</td>
<td>0.11</td>
</tr>
<tr>
<td>258/07</td>
<td>M 703/89</td>
<td>F 77790</td>
<td>SS × HS</td>
<td>34</td>
<td>2.55</td>
<td>3.6</td>
<td>0.13</td>
</tr>
<tr>
<td>265/07</td>
<td>R 575</td>
<td>F 77790</td>
<td>SS × HS</td>
<td>39</td>
<td>3.05</td>
<td>1.4</td>
<td>0.08</td>
</tr>
<tr>
<td>1197/03</td>
<td>S 17</td>
<td>M 1246/84</td>
<td>MS × MS</td>
<td>39</td>
<td>1.75</td>
<td>3.4</td>
<td>0.11</td>
</tr>
<tr>
<td>1293/03</td>
<td>S 17</td>
<td>R 570</td>
<td>MS × HS</td>
<td>38</td>
<td>2.1</td>
<td>2.4</td>
<td>0.12</td>
</tr>
<tr>
<td>275/07</td>
<td>S 17</td>
<td>F 77790</td>
<td>MS × HS</td>
<td>40</td>
<td>1.75</td>
<td>2.9</td>
<td>0.24</td>
</tr>
<tr>
<td>1228/03</td>
<td>M 695/69</td>
<td>M 1246/84</td>
<td>S × MS</td>
<td>40</td>
<td>2.15</td>
<td>2.2</td>
<td>0.12</td>
</tr>
<tr>
<td>1531/06</td>
<td>M 695/69</td>
<td>CP 62258</td>
<td>S × MS</td>
<td>39</td>
<td>3.3</td>
<td>2.7</td>
<td>0.11</td>
</tr>
<tr>
<td>1525/06</td>
<td>M 695/69</td>
<td>F 77790</td>
<td>S × HS</td>
<td>40</td>
<td>2.15</td>
<td>1.7</td>
<td>0.11</td>
</tr>
<tr>
<td>1314/03</td>
<td>M 695/69</td>
<td>R 570</td>
<td>S × HS</td>
<td>40</td>
<td>2.5</td>
<td>2.4</td>
<td>0.11</td>
</tr>
</tbody>
</table>

*T-tolerant, SS-slightly susceptible, MS-moderately susceptible, S-susceptible, HS-highly susceptible

**Value calculated from observations in pots of parent varieties from Table 1.

However, the frequency distributions of progeny within tolerance classes for the families pooled over replicates reveals better appreciation of the tolerance levels of the progenies within families (Table 3).

Table 3—Frequency distribution (%) of progenies within tolerance classes for families evaluated for a mix of herbicide in pots.

<table>
<thead>
<tr>
<th>Family reference</th>
<th>Female parent</th>
<th>Male parent</th>
<th>Tolerance category*</th>
<th>Tolerant (T)</th>
<th>Slightly susceptible (SS)</th>
<th>Moderately susceptible (MS)</th>
<th>Susceptible (S)</th>
<th>Highly susceptible (HS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1577/06</td>
<td>M 1400/86</td>
<td>M 2343/77</td>
<td>T × MS</td>
<td>0</td>
<td>30.8</td>
<td>48.7</td>
<td>20.5</td>
<td>0</td>
</tr>
<tr>
<td>1217/03</td>
<td>M 1176/77</td>
<td>M 1246/84</td>
<td>T × MS</td>
<td>2.5</td>
<td>55.0</td>
<td>40.0</td>
<td>2.5</td>
<td>0</td>
</tr>
<tr>
<td>1287/03</td>
<td>M 1176/77</td>
<td>R 570</td>
<td>T × HS</td>
<td>0</td>
<td>47.5</td>
<td>27.5</td>
<td>25.0</td>
<td>0</td>
</tr>
<tr>
<td>1304/03</td>
<td>M 1400/86</td>
<td>R 570</td>
<td>T × HS</td>
<td>0</td>
<td>20.5</td>
<td>23.1</td>
<td>38.5</td>
<td>17.9</td>
</tr>
<tr>
<td>1225/03</td>
<td>R 575</td>
<td>M 1246/84</td>
<td>SS × MS</td>
<td>0</td>
<td>10.3</td>
<td>59.0</td>
<td>28.2</td>
<td>2.6</td>
</tr>
<tr>
<td>1574/06</td>
<td>M 744/70</td>
<td>M 2343/77</td>
<td>SS × MS</td>
<td>11.1</td>
<td>52.8</td>
<td>36.1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>258/07</td>
<td>M 703/89</td>
<td>F 77790</td>
<td>SS × HS</td>
<td>8.8</td>
<td>44.1</td>
<td>41.2</td>
<td>5.9</td>
<td>0</td>
</tr>
<tr>
<td>265/07</td>
<td>R 575</td>
<td>F 77790</td>
<td>SS × HS</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>43.6</td>
<td>56.4</td>
</tr>
<tr>
<td>1197/03</td>
<td>S 17</td>
<td>M 1246/84</td>
<td>MS × MS</td>
<td>0</td>
<td>48.7</td>
<td>41.0</td>
<td>10.3</td>
<td>0</td>
</tr>
<tr>
<td>1293/03</td>
<td>S 17</td>
<td>R 570</td>
<td>MS × HS</td>
<td>0</td>
<td>2.6</td>
<td>44.7</td>
<td>39.5</td>
<td>13.2</td>
</tr>
<tr>
<td>275/07</td>
<td>S 17</td>
<td>F 77790</td>
<td>MS × HS</td>
<td>22.5</td>
<td>12.5</td>
<td>22.5</td>
<td>12.5</td>
<td>30.0</td>
</tr>
<tr>
<td>1228/03</td>
<td>M 695/69</td>
<td>M 1246/84</td>
<td>S × MS</td>
<td>0</td>
<td>2.5</td>
<td>32.5</td>
<td>45.0</td>
<td>20.0</td>
</tr>
<tr>
<td>1531/06</td>
<td>M 695/69</td>
<td>CP 62258</td>
<td>S × MS</td>
<td>2.6</td>
<td>5.1</td>
<td>56.4</td>
<td>35.9</td>
<td>0</td>
</tr>
<tr>
<td>1525/06</td>
<td>M 695/69</td>
<td>F 77790</td>
<td>S × HS</td>
<td>0</td>
<td>0</td>
<td>12.5</td>
<td>40.0</td>
<td>47.5</td>
</tr>
<tr>
<td>1314/03</td>
<td>M 695/69</td>
<td>R 570</td>
<td>S × HS</td>
<td>0</td>
<td>5.0</td>
<td>32.5</td>
<td>55.0</td>
<td>7.5</td>
</tr>
</tbody>
</table>

*T-tolerant, SS-slightly susceptible, MS-moderately susceptible, S-susceptible, HS-highly susceptible
Generally, crosses involving a tolerant or a slightly susceptible parent yielded a higher frequency of progenies in the T and SS classes. This was particularly prominent in the crosses 1217/03, 1287/03, 1574/06, and 258/07. Only the cross 265/07 with R 575 as the female parent produced progenies that were all susceptible or highly susceptible. Cross 1225/03, which also had R 575 as the female parent, gave progenies which were predominantly grouped in the MS and S classes. It appears that the female parent can exert a more pronounced influence on the tolerance level of its progeny suggesting the involvement of cytoplasmic inheritance. Cross 275/07 gave a wide distribution of progenies in all classes with a relatively high percentage in the tolerant class. The absolute distribution of progenies grouped in three sensitivity classes, T/SS, MS and S/HS, and the percentage of progenies that fits in each of the three classes for crosses grouped in different categories is shown in Table 4.

Table 4—Absolute number of progenies grouped within three classes, T/SS, MS and S/HS, for their reaction to herbicide mix and percentage of progenies within these classes for different categories of crosses grouped together.

<table>
<thead>
<tr>
<th>Cross</th>
<th>Female</th>
<th>Male</th>
<th>Category*</th>
<th>T/SS</th>
<th>MS</th>
<th>S/HS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1577/06</td>
<td>M 1400/86</td>
<td>M 2343/77 T × MS</td>
<td>12</td>
<td>19</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>1217/03</td>
<td>M 1176/77</td>
<td>M 1246/84 T × MS</td>
<td>23</td>
<td>16</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1225/03</td>
<td>R 575</td>
<td>M 1246/84 SS × MS</td>
<td>4</td>
<td>23</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>1574/06</td>
<td>M 744/70</td>
<td>M 2343/77 SS × MS</td>
<td>23</td>
<td>13</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total (%)</td>
<td>40.3</td>
<td>46.1</td>
<td>13.6</td>
</tr>
<tr>
<td>1287/03</td>
<td>M 1176/77</td>
<td>R 570 T × HS</td>
<td>19</td>
<td>11</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>1304/03</td>
<td>M 1400/86</td>
<td>R 570 T × HS</td>
<td>8</td>
<td>9</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>258/07</td>
<td>M 703/89</td>
<td>F 77790 SS × HS</td>
<td>18</td>
<td>14</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>265/07</td>
<td>R 575</td>
<td>F 77790 SS × HS</td>
<td>0</td>
<td>0</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total (%)</td>
<td>29.6</td>
<td>22.4</td>
<td>48.0</td>
</tr>
<tr>
<td>1197/03</td>
<td>S 17</td>
<td>M 1246/84 MS × MS</td>
<td>19</td>
<td>16</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>1228/03</td>
<td>M 695/69</td>
<td>M 1246/84 S × MS</td>
<td>1</td>
<td>13</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>1531/06</td>
<td>M 695/69</td>
<td>CP 62258 S × MS</td>
<td>3</td>
<td>22</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>1293/03</td>
<td>S 17</td>
<td>R 570 MS × HS</td>
<td>1</td>
<td>17</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>275/07</td>
<td>S 17</td>
<td>F 77790 MS × HS</td>
<td>14</td>
<td>9</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total (%)</td>
<td>19.4</td>
<td>39.3</td>
<td>41.3</td>
</tr>
<tr>
<td>1525/06</td>
<td>M 695/69</td>
<td>F 77790 S × HS</td>
<td>0</td>
<td>5</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>1314/03</td>
<td>M 695/69</td>
<td>R 570 S × HS</td>
<td>2</td>
<td>13</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total (%)</td>
<td>2.5</td>
<td>22.5</td>
<td>75.0</td>
</tr>
</tbody>
</table>

* T-tolerant, SS-slightly susceptible, MS-moderately susceptible, S-susceptible, HS-highly susceptible

Crosses between T/SS × MS parents produced about 40% and 46% of progenies in the T/SS and MS classes respectively. Those between T/SS × HS produced about 30% and 22% of progenies in the T/SS and MS classes respectively. Crosses between MS × MS, S and HS parents gave about 19% and 39% of progenies grouped in T/SS and MS classes respectively and nearly 41% in the S/HS class. S × HS crosses produced a very high proportion (75%) of progenies in the S/HS classes. It is clear that the degree of susceptibility to herbicide increases with the degree of susceptibility of the parental combination. Nearly all crosses had an appreciable percentage of progeny in the moderately susceptible class. A clear-cut segregation towards either T/SS or S/HS groups was not evident that could indicate the action of some major genes. It is possible that the two herbicides in the mix might have different genetic control that masked the action of any major gene effect. Transgenic segregation for herbicide resistance (bar) has been demonstrated in sugarcane (Butterfield et al., 2002) and a cultivar transformed with the pat gene, conferring resistance to the herbicide Buster (glufosinate ammonium) was stably expressed during three rounds of vegetative propagation (Leibbrandt and Snyman, 2003).
In addition to the genetic control underlining resistance to herbicide, morphological attributes such as epicuticular wax of leaf surface may influence tolerance level in varieties.

Bi-parental progeny analysis revealed highly significant differences between families for tolerance level to the herbicide mix. Partitioning of variances showed a high proportion of additive genetic variance and high narrow-sense heritability and low standard error estimates. (Table 5).

Table 5—Variance ratios, components of variances and heritability estimates derived from bi-parental progeny analysis of 15 families for their tolerance to herbicide mix.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>MS</th>
<th>v.r.</th>
<th>F Prob</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between FS family MS Residual MS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sigma^2_B$</td>
<td>14</td>
<td>566</td>
<td>19.176</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>$\sigma^2_W$</td>
<td>0.4787</td>
<td>0.6003</td>
<td>31.94</td>
<td></td>
</tr>
<tr>
<td>$V_A$</td>
<td>0.9575</td>
<td>0.6003</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_E$</td>
<td>0.1213</td>
<td>31.94</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_P$</td>
<td>1.0788</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heritability</td>
<td>0.89</td>
<td>0.6003</td>
<td></td>
<td></td>
</tr>
<tr>
<td>se $h^2_n$</td>
<td>0.19</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

However, the heritability value is somewhat inflated from the fact that a number of parents were repeated in a number of crosses. A wider range of unrelated crosses was not available on account of lower fertility levels of some crosses, insufficient pollen-shedding varieties and asynchronous flowering. Nevertheless, the study does indicate that the tolerance/sensitivity level of the progenies to the herbicide mix can be predicted reasonably well on the basis of the reaction levels of their parents and breeding for herbicide tolerance is possible.

Conclusion

This study indicated a wide variation in herbicide tolerance within the parent pool considered with about one-third of the parents rated as susceptible to the herbicide tank-mix diuron + Actril-DS® when evaluation was carried out in pots. There was a moderately high correlation between the tolerance level of varieties measured in pots and in the field, although the phytotoxicity appeared to be less severe at field level. The measurement of herbicide tolerance levels in pots by the precision sprayer can constitute a quick and economic means for assessing the relative sensitivity of varieties to herbicides. Generally, crosses between T/SS × MS parents produced about 40% and 46% of progenies in the T/SS and MS classes respectively. Conversely, progeny derived from susceptible × highly susceptible (S × HS) parents produced nearly 75% of progenies in the susceptible and the highly susceptible classes grouped together. No clear-cut evidence of a major gene to herbicide mix was evident and the transmission of tolerance level to the mixture of herbicide approached an additive model indicating that tolerance/sensitivity level of the progenies to the herbicide tank-mix can be predicted reasonably well on the basis of the reaction levels of their parents.

REFERENCES


TOLÉRANCE DES GÉNITEURS DE LA CANNE À SUCRE AUX HERBICIDES 
ET SA TRANSMISSION À LA DESCENDANCE

Par

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MOTS CLÉS: Actril DS®, Diuron, Hérédité, Post-Émergence, Tolérance aux Herbicides.

Résumé

Les variétés de canne à sucre ayant un parent en commun ont souvent montré un niveau plus ou moins similaire de tolérance au mélange Diuron et Actril-DS®. Une étude a été entreprise dans le but d’évaluer la tolérance des géniteurs de la canne à sucre, utilisés fréquemment dans le programme d’hybridation du MSIRI, aux herbicides. Un total de soixante géniteurs établis en pots et ensuite transplantés au champ ont été évalués pour leur tolérance à un mélange d’herbicides. Des croisements ont été réalisés avec des parents éprouvés pour leur réaction aux herbicides et 15 familles, comprenant chacune 40 plantules, ont été par la suite évaluées pour leur réaction au mélange d’herbicides. Les parents ont démontré des différences significatives pour leur niveau de tolérance et ils ont été classifiés selon les niveaux suivants: tolérant (T) 10%; légèrement sensible (SS) 34%; modérément sensible (MS) 25%; sensible (S) 25%; hautement sensible (HS) 7%. La corrélation modérément élevée obtenue entre le niveau de tolérance des parents mesurés en pots et au champ démontre qu’une évaluation de la réponse aux herbicides des génotypes en pots peut fournir des indications assez fiables sur leur niveau de tolérance au champ. Les familles ont également démontré des différences significatives pour leur niveau de tolérance. Généralement, les croisements entre les parents T/SS x MS ont produit environ 40% et 46% de leurs descendants dans les classes T/SS et MS respectivement. À l’opposé, les croisements entre parents S x HS ont produit un pourcentage très élevé (75%) de leurs descendants dans les classes S/HS. Le niveau de sensibilité augmente avec le niveau de sensibilité des combinaisons parentales. Une distinction claire des descendants soit en classe T/SS ou S/HS n’était pas évidente ce qui pouvait présager la contribution d’un gène majeur. La décomposition de la variance génétique démontre une contribution importante de la variance additive et une héritabilité au sens strict relativement élevée et indique que la production de nouvelles générations de génotypes tolérantes aux herbicides est possible.
fueron plantados en macetas y luego trasplantados a ensayos replicados en el campo para evaluar su tolerancia a la mezcla de herbicida. Se realizaron cruzamientos con algunos parentales que presentan alguna Resistencia y 15 familias, con un total de 40 plántulas en cada cruza, las que fueron evaluadas también a la misma mezcla del tanque de herbicida. Los parentales fueron significativamente diferentes a la mezcla del herbicida, clasificándose como: tolerante (T) 10%; poco susceptible (SS) 34%; moderadamente susceptible (MS) 25%; susceptible (S) 25%; altamente susceptible (HS) 7%. La correlación fenotípica del grado de tolerancias a la mezcla herbicida evaluada en macetas y en el campo fue moderadamente alta, indicando que las pruebas en macetas podrían proveer información útil sobre la expresión a la tolerancia en el campo. Las familias también disfirieron significativamente en el campo. Generalmente cruzas entre parentales T/SS x MS produjeron alrededor de 40% y 46% de progenies T/SS y MS respectivamente. Contrariamente, los cruzamientos S x HS produjeron una alta proporción (75%) de progenies en el S/HS. El grado de susceptibilidad al herbicida se incrementa con el grado de susceptibilidad de la combinación parental. No se evidenció una clara segregación hacia grupos T/SS o S/HS que indicaría la acción de un gen mayor. Al dividir las variancias se observó un claro efecto aditivo y una alta heredabilidad en sentido estrecho y la posibilidad de realizar mejoramiento para este carácter a través de escoger las variedades para parentales.
GENETIC BASE BROADENING OF SUGARCANE (SACCHARUM SPP.) BY INTROGRESSION OF GENES THROUGH INTERGENERIC HYBRIDISATION

By

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KEYWORDS: Erianthus, Nobilisation, Intergeneric Hybrid.

Abstract

SUGARCANE (Saccharum spp.) is one of the crops for which interspecific hybridisation has provided a major breakthrough for its improvement. However, intergeneric hybridisation has been gaining importance to broaden the genetic base and to obtain commercially useful traits and simultaneously increase the total biomass. The benefits derived from the use of wild species like S. spontaneum have been realised since the early 1900s, and the compatibility of Saccharum officinarum with Erianthus is now being explored to incorporate disease-resistance genes. This genus also has a great potential for vigour, better ratoonability and tolerance to environmental stresses. In E.I.D Parry (India) Ltd, R & D Centre, attempts were made through a conventional breeding program to introduce these traits into commercial sugarcane cultivars. The true nature of these hybrids is confirmed by morphological features like leaf orientation, leaf striping, stalk length, stalk thickness, internode length, stalk colour and bio-chemical features like sucrose, fibre content and analysis through molecular techniques. Selected intergeneric hybrids were used for backcrosses to develop commercial cultivars.

Introduction

Sugarcane breeding has come a long way from the time it was started by the Dutch in Indonesia. The importance of breeding was realised by many industries and thus sugarcane breeding was commenced in earnest with Saccharum officinarum clones collected from Papua New Guinea, Irian Jaya and the Pacific Islands. Badila and Korpi, along with striped Singapore, Malabar Red etc. (Deer, 1921) remained under commercial cultivation until the 1920s when hybrids started to overtake these S. officinarum clones. During the initial period of sugarcane breeding, the improvement of sugarcane relied on the selection of naturally occurring variants of S. officinarum obtained by expeditions to its centre of origin in New Guinea (Ramdoyal and Badaloo, 2002).

In the late 1800s and the early 1900s, interspecific hybridisation with wild species (Saccharum spontaneum L.) provided a major break-through in cane yield and sugar improvement. The Dutch used S. spontaneum clone Kassoer in their breeding program and produced POJ2878, the Java wonder cane. This was followed by the Indians who used a S. spontaneum from Coimbatore and released a nobilised cane, Co205. It was not until after the Second World War that serious effort went into the use of S. spontaneum. A concentrated and systematic effort was made by the CSR Company in Australia and Fiji to nobilise superior S. spontaneum clones with S. officinarum (Roach, 1971; Krishnamurthi, 1987). Some of these F1 populations are available in Fiji and perhaps Macknade Queensland. In Canal Point USA, another program was undertaken to nobilise Thai S. spontaneum (Millr et al., 2005).

It was generally considered that the noble canes would contribute the ability to store sucrose, while the vegetative vigour, good ratooning and disease resistance would come from S. spontaneum. Although the progress was initially good, by the late 1960s it was realised that the...
exceedingly narrow genetic base of the existing clones was beginning to impede further progress (Kennedy, 2001). To break this yield barrier, sugarcane breeders attempted to generate intergeneric hybrids between *S. officinarum* and *Erianthus*. Among the several species of *Erianthus* present in both the old and new world, *E. arundinaceus* and *E. procerus* have a wider distribution in India, China, Myanmar, Thailand, Philippines, Indonesia and New Guinea, while the other species have a restricted distribution (Nair and Praneetha, 2006).

Mukherjee (1958) assigned the origin of the species to the Indo-Myanmar-China region where the species is extensively distributed. The species subsequently spread to the adjoining areas in South and South-East Asia. This is the only cane forming species among *Erianthus* and has enormous potential as a contributor of germplasm to current cultivars for better ratoonability, vigour and tolerance to environmental stresses such as drought and flooding.

Numerous attempts have been made to cross *E. arundinaceus* with sugarcane to introduce these characters into modern cultivars. The need to broaden the genetic base, given the spectra of yield stagnation, and the need to introgress specific characters from wild and associated genera, raised the interest in cane breeding. Intergeneric hybridisation provides the required genetic variability by incorporating useful genes from wild relatives into commercial sugarcane. Further, back crossing with high-sucrose commercial cultivars was essential to develop commercial varieties.

During the 1960s, two clones i.e. one of *Erianthus procerus* and another *E. bengalense* were exported from Coimbatore into Fiji (courtesy T.V. Sreenivasan and M. Naidu) and extensive studies were undertaken with regard to flowering, anthesis, pollen and compatibilities. Crosses were made using *S. officinarum*, Korpi and Badila, with *E. procerus* in Fiji. A series of hybrids i.e. LF 63-51, LF 63-55, LF 63-70, LF 63-71 were selected and used. These hybrids were identified by plant type, internode length and inflorescence shape.

Apart from researches in Fiji, Sreenivasan (pers. comm., 1993) was one of the first to attempt crosses with *Erianthus* and obtained good progenies. He also indicated the chromosome elimination effect in *Erianthus* progenies. One of the major obstacles in the past has been the identification of true hybrids using morphological characters. Sometimes this method of identification appears to be misleading the breeders. To overcome this problem, molecular diagnostic tools have recently been developed for use in sugarcane to identify the putative intergeneric hybrids (D’Hont et al., 1995; Alix et al., 1998, 1999). These tools include sequence-tagged PCR to identify true hybrids at the seedling stage, and genomic *in situ* hybridisation (GISH) to characterise the chromosome complement of hybrids (Piperidis et al., 2000).

A planned intergeneric hybridisation program was started in E.I.D Parry (India) Ltd. to exploit the potential of *Erianthus arundinaceus* to develop commercial cultivars (Krishnamurthi et al., 2004).

**Materials and methods**

**Materials used**

The female parents used were 16 pure *S. officinarum* and 4 commercial cultivars. Four accessions of *Erianthus arundinaceus* were used as males (from Thailand and Indonesia) in 2000–2001 crossing seasons at Bangalore. Clones with less than 5% viable pollen were chosen as females in the crossing program. 63 cross combinations were made and 1625 seedlings were produced. Out of these cross combinations, the three cross combinations viz., Badila x *E. arundinaceus*, Korpi x *E. arundinaceus* and CoC 671 x *E. arundinaceus* produced 111 seedlings subjected to selection based on morphological traits. Twelve putative hybrids were selected for further evaluation.

**Flowering and synchronisation of flowering**

Sugarcane is an intermediate day plant that will flower in response to gradually increasing night length. Most *E. arundinaceus* clones in our germplasm collection flower together with *S.
officinarum cultivars. Based on the need, flowering was synchronised using the techniques developed by Daniels and Krishnamurthi (1967) and Krishnamurthi (1987). The flowering was arrested with night lighting and induction achieved by reducing the day length.

**Crossing techniques**

Crossing with *Erianthus arundinaceus* was not easy as it had to be carried out with precision to overcome many hurdles. The pollen from *Erianthus* was collected at 5.30 am and pollinated before the pollen shedding in the female parent. The pollen collection, pollen viability testing and handling, pollination, fuzz collection, fuzz processing, seedling raising, selection and further crossings were carried out as per Krishnamurthi *et al.* (2006).

**Field evaluation**

The hybrid seedlings were sown in trays and transplanted into pro-trays prior to field planting. The field planting was in rows 1.2 m apart spaced at 60 cm. The selection was carried out based on morphological traits coupled with hand refractometer brix %. The selected hybrids were multiplied in 5.0 m × 1 row plots for seedcane purposes.

The selected intergeneric hybrids were planted in a plot size of 4 rows x 5 m x 4 replications along with female and male parents using RBD design in the 2005–06 season at Pugalur, Tamil Nadu, India. Regular agricultural operations were carried out for this trial. The field characters viz., stalk length (cm), number of internodes, internode length (cm), internode thickness (cm), stalk number per square metre, were collected 10 months after planting. The stalk weight (kg) and cane yield data were collected at the time of harvest (Rajeswari, 2004). The quality parameters viz., brix %, pol %, purity %, fibre % and POCS % were estimated in the laboratory using CSR methods. The analysis was performed on five stalk samples, which were collected at the age of 12 months.

**Molecular analysis**

For the confirmation of the hybrid nature of the F₁ populations, molecular analysis was carried out at the Sugarcane Breeding Institute (SBI), Coimbatore, India. The hybrids were screened along with their male and female parents using sugarcane SSR primer pairs. The amplified products were analysed on PAGE gels with silver staining.

**Results and discussion**

Sugarcane flowering in Bangalore, India is between November and mid-January. The *in vitro* pollen germination test indicated that the pollen germination was ranging between 30% and 90%. The same was found to be true for the *in-vivo* test. It was found that *Erianthus* shed pollen at least three times a day i.e 5.30 am, 9.00 am and 3.00 pm. The pollen produced at 9.00 am and 3.00 pm showed low viability when cultured *in vitro*. The various hybrids produced viable pollen in abundance.

One thousand six hundred twenty five seedlings were produced from 63 cross combinations. Out of these, twelve putative hybrids from the following three cross combinations were used for the field and quality analysis (Table 1). No genuine hybrids were identified from other crosses.

<table>
<thead>
<tr>
<th>Female parent</th>
<th>Male parent</th>
<th>No. of seedlings produced</th>
<th>No. of selected putative hybrids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Badila</td>
<td><em>E. arundinaceus</em></td>
<td>23</td>
<td>4 (PIH 01-0010, PIH 01-3246, PIH 01-3315, PIH 01-3317)</td>
</tr>
<tr>
<td>Korpi</td>
<td><em>E. arundinaceus</em></td>
<td>32</td>
<td>3 (PIH 01-3231, PIH 01-3227, PIH 01-3228)</td>
</tr>
<tr>
<td>CoC 671 cultivar</td>
<td><em>E. arundinaceus</em></td>
<td>56</td>
<td>5 (PIH 01-0135, PIH 01-0080, PIH 00-0082, PIH 01-0127, PIH 01-0480)</td>
</tr>
</tbody>
</table>
The metric field traits like stalk length (cm), number of internodes, internode length (cm), internode thickness (cm), stalk number per square metre, stalk weight (kg) and cane yield (t/ha) observed from parents and hybrids are presented in Table 2. The selected hybrid progenies exhibit early vigour, recorded higher cane yield and were better in all morphological traits when compared to parents in the research plots.

### Table 2—Field data of parents and intergeneric hybrids.

<table>
<thead>
<tr>
<th>Parents and hybrids</th>
<th>Stalk length (cm)</th>
<th>No.of internodes</th>
<th>Internode length (cm)</th>
<th>Internode thickness (cm)</th>
<th>Stalk no/sq.m</th>
<th>Stalk weight (kg)</th>
<th>Yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Badila</td>
<td>175.3</td>
<td>18</td>
<td>8.9</td>
<td>3.9</td>
<td>6</td>
<td>3</td>
<td>88.0</td>
</tr>
<tr>
<td>E. arundinaceus</td>
<td>240.4</td>
<td>13</td>
<td>18.9</td>
<td>1.9</td>
<td>30</td>
<td>1.1</td>
<td>100.3</td>
</tr>
<tr>
<td>PIH 01-0010</td>
<td>179.9</td>
<td>21</td>
<td>12.2</td>
<td>2.8</td>
<td>12</td>
<td>2.2</td>
<td>107.8</td>
</tr>
<tr>
<td>PIH 01-3246</td>
<td>195.8</td>
<td>20</td>
<td>15.1</td>
<td>2.6</td>
<td>15</td>
<td>2.3</td>
<td>113.8</td>
</tr>
<tr>
<td>PIH 01-3315</td>
<td>203.4</td>
<td>23</td>
<td>10.8</td>
<td>3</td>
<td>13</td>
<td>2.2</td>
<td>113.0</td>
</tr>
<tr>
<td>PIH 01-3317</td>
<td>190.5</td>
<td>21</td>
<td>14.1</td>
<td>3.1</td>
<td>17</td>
<td>2.4</td>
<td>118.0</td>
</tr>
<tr>
<td>Korpi</td>
<td>165.4</td>
<td>17</td>
<td>9.4</td>
<td>3.5</td>
<td>8</td>
<td>2.5</td>
<td>100.5</td>
</tr>
<tr>
<td>E. arundinaceus</td>
<td>240.4</td>
<td>13</td>
<td>18.9</td>
<td>1.9</td>
<td>30</td>
<td>1.1</td>
<td>100.3</td>
</tr>
<tr>
<td>PIH 01-3231</td>
<td>205.9</td>
<td>19</td>
<td>11.2</td>
<td>3.1</td>
<td>15</td>
<td>2.2</td>
<td>146.3</td>
</tr>
<tr>
<td>PIH 01-3227</td>
<td>200.4</td>
<td>22</td>
<td>10.9</td>
<td>3</td>
<td>18</td>
<td>2.4</td>
<td>155.3</td>
</tr>
<tr>
<td>PIH 01-3228</td>
<td>209.9</td>
<td>23</td>
<td>12.8</td>
<td>2.9</td>
<td>17</td>
<td>2.5</td>
<td>139.3</td>
</tr>
<tr>
<td>CoC 67-1</td>
<td>195.5</td>
<td>22</td>
<td>10.6</td>
<td>3.3</td>
<td>14</td>
<td>2.2</td>
<td>121.3</td>
</tr>
<tr>
<td>E. arundinaceus</td>
<td>240.4</td>
<td>13</td>
<td>18.9</td>
<td>1.9</td>
<td>30</td>
<td>1.1</td>
<td>100.3</td>
</tr>
<tr>
<td>PIH 00-0135</td>
<td>210.4</td>
<td>24</td>
<td>14.2</td>
<td>3.1</td>
<td>18</td>
<td>2.3</td>
<td>146.0</td>
</tr>
<tr>
<td>PIH 00-0080</td>
<td>230.7</td>
<td>26</td>
<td>12.4</td>
<td>2.9</td>
<td>22</td>
<td>2.5</td>
<td>162.8</td>
</tr>
<tr>
<td>PIH 00-0082</td>
<td>205.2</td>
<td>25</td>
<td>11.9</td>
<td>2.9</td>
<td>26</td>
<td>2.5</td>
<td>155.3</td>
</tr>
<tr>
<td>PIH 00-0127</td>
<td>200.7</td>
<td>24</td>
<td>15.1</td>
<td>3.2</td>
<td>21</td>
<td>2.3</td>
<td>169.8</td>
</tr>
<tr>
<td>PIH 00-0480</td>
<td>235.5</td>
<td>28</td>
<td>14.9</td>
<td>3.1</td>
<td>25</td>
<td>2.1</td>
<td>171.0</td>
</tr>
</tbody>
</table>

The ANOVA (Table 3) revealed that there are significant differences among the entries tested which indicates the difference among the parents and hybrids. All hybrids tested here showed intermediate values between the parents for almost all traits studied.

### Table 3—ANOVA of metric field data.

<table>
<thead>
<tr>
<th>SV</th>
<th>df</th>
<th>Mean squares</th>
<th>Stalk length</th>
<th>No.of internodes</th>
<th>Internode length</th>
<th>Internode thickness</th>
<th>Stalk no/sq.m</th>
<th>Stalk weight</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rep</td>
<td>3</td>
<td>49.92</td>
<td>0.69</td>
<td>2.98</td>
<td>0.04</td>
<td>5.62</td>
<td>0.01</td>
<td>7.0</td>
<td></td>
</tr>
<tr>
<td>Treat</td>
<td>15</td>
<td>1687.97**</td>
<td>5.83**</td>
<td>26.36**</td>
<td>0.71**</td>
<td>164.12**</td>
<td>0.58**</td>
<td>2920.6**</td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>45</td>
<td>13.38</td>
<td>2.24</td>
<td>0.47</td>
<td>0.09</td>
<td>2.11</td>
<td>0.04</td>
<td>6.9</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>63</td>
<td>413.83</td>
<td>14.93</td>
<td>6.75</td>
<td>0.23</td>
<td>40.85</td>
<td>0.17</td>
<td>700.7</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>–</td>
<td>202.80</td>
<td>21.66</td>
<td>12.71</td>
<td>3.02</td>
<td>17.31</td>
<td>2.29</td>
<td>131.8</td>
<td></td>
</tr>
<tr>
<td>SEd</td>
<td>–</td>
<td>2.59</td>
<td>1.06</td>
<td>0.48</td>
<td>0.21</td>
<td>1.03</td>
<td>0.15</td>
<td>1.88</td>
<td></td>
</tr>
<tr>
<td>CD(0.01)</td>
<td>–</td>
<td>6.96</td>
<td>2.85</td>
<td>1.30</td>
<td>0.56</td>
<td>2.76</td>
<td>0.40</td>
<td>5.03</td>
<td></td>
</tr>
<tr>
<td>CV%</td>
<td>–</td>
<td>1.80</td>
<td>6.92</td>
<td>5.39</td>
<td>9.85</td>
<td>8.40</td>
<td>9.28</td>
<td>2.00</td>
<td></td>
</tr>
</tbody>
</table>

(** Significance at 1% level)
The quality data (Brix %, Pol % in juice, purity %, fibre % and pure obtainable cane sugar (POCS %)) were collected for all parents (except *Erianthus*) and hybrids. Since there is no extractable juice in the *E. arundinaceus* stalks, only fibre data were recorded.

The mean values of the replicated samples are presented in Table 4. Most of the intergeneric hybrids showed higher fibre % and lower POCS % compared to *S. officinarum* clones.

### Table 4—Quality data of parents and intergeneric hybrids.

<table>
<thead>
<tr>
<th>Parents and Hybrids</th>
<th>Brix %</th>
<th>Pol %</th>
<th>Purity %</th>
<th>Fibre %</th>
<th>POCS %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Badila</td>
<td>18.2</td>
<td>16.1</td>
<td>88.46</td>
<td>11</td>
<td>12.46</td>
</tr>
<tr>
<td><em>E. arundinaceus</em></td>
<td></td>
<td></td>
<td></td>
<td>38.4</td>
<td></td>
</tr>
<tr>
<td>PIH 01-0010</td>
<td>14.6</td>
<td>12.5</td>
<td>85.62</td>
<td>17.2</td>
<td>8.76</td>
</tr>
<tr>
<td>PIH 01-3246</td>
<td>15.4</td>
<td>13.2</td>
<td>85.71</td>
<td>19.1</td>
<td>9.03</td>
</tr>
<tr>
<td>PIH 01-3315</td>
<td>14</td>
<td>11.8</td>
<td>84.29</td>
<td>17.5</td>
<td>8.15</td>
</tr>
<tr>
<td>PIH 01-3317</td>
<td>16.3</td>
<td>13.4</td>
<td>82.21</td>
<td>18.4</td>
<td>8.99</td>
</tr>
<tr>
<td>Korpi</td>
<td>19.2</td>
<td>17</td>
<td>88.54</td>
<td>12</td>
<td>13.01</td>
</tr>
<tr>
<td><em>E. arundinaceus</em></td>
<td></td>
<td></td>
<td></td>
<td>38.4</td>
<td></td>
</tr>
<tr>
<td>PIH 01-3231</td>
<td>16.2</td>
<td>14.2</td>
<td>87.65</td>
<td>17.4</td>
<td>10.08</td>
</tr>
<tr>
<td>PIH 01-3227</td>
<td>15.9</td>
<td>13.5</td>
<td>84.91</td>
<td>18.3</td>
<td>9.28</td>
</tr>
<tr>
<td>PIH 01-3228</td>
<td>16.3</td>
<td>13.3</td>
<td>81.60</td>
<td>19.4</td>
<td>8.76</td>
</tr>
<tr>
<td>CoC 67-1</td>
<td>18.0</td>
<td>17.3</td>
<td>96.11</td>
<td>12.5</td>
<td>13.80</td>
</tr>
<tr>
<td><em>E. arundinaceus</em></td>
<td></td>
<td></td>
<td></td>
<td>38.4</td>
<td></td>
</tr>
<tr>
<td>PIH 00-0135</td>
<td>16.1</td>
<td>13.7</td>
<td>85.09</td>
<td>18.4</td>
<td>9.41</td>
</tr>
<tr>
<td>PIH 00-0080</td>
<td>15.8</td>
<td>14.2</td>
<td>89.87</td>
<td>17.8</td>
<td>10.19</td>
</tr>
<tr>
<td>PIH 00-0082</td>
<td>15.8</td>
<td>14.1</td>
<td>89.24</td>
<td>20.1</td>
<td>9.77</td>
</tr>
<tr>
<td>PIH 00-0127</td>
<td>16.3</td>
<td>13.5</td>
<td>82.82</td>
<td>19.7</td>
<td>8.95</td>
</tr>
<tr>
<td>PIH 00-0480</td>
<td>15.8</td>
<td>14.6</td>
<td>92.41</td>
<td>18.6</td>
<td>10.54</td>
</tr>
</tbody>
</table>

The ANOVA (Table 5) revealed that all entries tested are significantly different for these traits.

### Table 5—ANOVA of quality data.

<table>
<thead>
<tr>
<th>SV</th>
<th>df</th>
<th>Brix %</th>
<th>Pol %</th>
<th>Purity %</th>
<th>Fibre %</th>
<th>POCS %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rep</td>
<td>3</td>
<td>0.07</td>
<td>0.01</td>
<td>2.66</td>
<td>0.04</td>
<td>3</td>
</tr>
<tr>
<td>Treat</td>
<td>14</td>
<td>7.10**</td>
<td>9.58**</td>
<td>62.52**</td>
<td>11.49**</td>
<td>15</td>
</tr>
<tr>
<td>Error</td>
<td>42</td>
<td>0.03</td>
<td>0.05</td>
<td>2.32</td>
<td>0.08</td>
<td>45</td>
</tr>
<tr>
<td>Total</td>
<td>59</td>
<td>1.71</td>
<td>2.31</td>
<td>16.63</td>
<td>2.78</td>
<td>63</td>
</tr>
<tr>
<td>Mean</td>
<td>16.26</td>
<td>14.16</td>
<td>86.97</td>
<td>10.08</td>
<td>18.49</td>
<td></td>
</tr>
<tr>
<td>SEd</td>
<td>0.12</td>
<td>0.16</td>
<td>0.17</td>
<td>1.07</td>
<td>0.19</td>
<td>–</td>
</tr>
<tr>
<td>CD(0.01)</td>
<td>0.33</td>
<td>0.48</td>
<td>2.91</td>
<td>0.53</td>
<td>0.57</td>
<td>–</td>
</tr>
<tr>
<td>CV%</td>
<td>1.06</td>
<td>1.66</td>
<td>1.75</td>
<td>2.75</td>
<td>1.62</td>
<td>–</td>
</tr>
</tbody>
</table>

(** Significance at 1% level)

The molecular work was carried out at the Sugarcane Breeding Institute (SBI), Coimbatore, Tamil Nadu, India. Until now, one hybrid PIH 01-3228 was confirmed by SSR markers specific to *Saccharum* and *Erianthus* (Figure 1).

In Figure 1, hybrids other than those reported in this paper are also shown. The confirmed hybrid has both *Saccharum* and *Erianthus* bands. The molecular characterisation of all hybrids is currently in progress.
In the process of *Erianthus* hybridisation, breeders have to handle issues such as anthesis of male parents which posed a major problem. *Erianthus* is unique in the time for anthesis which takes place at 5.30 am and the viability is more than 50–60%, whereas subsequent anthesis on the same day produces enough quantity of pollen but the viability is less than 10%; hence, pollination is ineffective. Moreover, the pollen has the habit of coagulation. Hence, viability is greatly reduced if not handled carefully. The second major problem encountered was incompatibility with most true *S. officinarum*. The few which give good progeny are *S. officinarum* clones, Korpi, Badila and a few NG clones. The incompatibility might be due to incongruity between the pollen and pistil of the two genera (Lee, 1995). Our experience indicates using commercials like CoC 67-1 and Co 86-032 as females produces a good number of hybrid seedlings.

Molecular techniques paved a new way for introgression of desirable genes from *Erianthus* to *Saccharum*. Other than *E. arundinaceus*, another species, *E. rockii*, has been identified by Chinese sugarcane breeders, and attempts were made to introgress with *S. officinarum*. Cai et al. (2005a) reported that *E. rockii* was distinct from other species of *Erianthus* and *Saccharum* species through SSR and AFLP markers. Verification of intergeneric hybrids of *E. rockii* and *Saccharum* using molecular markers was reported by Aitken et al. (2007) and they observed n+n transmission of chromosomes. Molecular confirmation of hybrids was reported by many scientists in the last few years. Cai et al. (2005b) confirmed the introgression of *E. arundinaceus* into sugarcane by identification of genuine BC₁ progeny from an F₁ intergeneric hybrid x *Saccharum* clone with molecular markers.

Chromosome elimination was also observed in intergeneric hybrids when analysed using genomic *in situ* hybridisation (GISH). Most of these intergeneric hybrids were sterile and unable to use for backcross (Piperidis et al., 2000) whereas the hybrids produced from this project are showing hybrid vigour and produce more than 30 to 40% viable pollen. One hybrid PIH 01-3315 (*Badila* x *Erianthus*) became male sterile and does not produce any viable pollen. Among all the hybrids, PIH 01-3228 (*Korpi* x *Erianthus*) was subjected to molecular analysis and proved to be a putative intergeneric hybrid (Figure1). These hybrids are being used for further backcrosses to develop commercial cultivars.

**Acknowledgements**

The authors are indeed grateful to all the staff for help and E.I.D. Parry for permission to publish the findings. Dr N.Vijayan Nair and Dr A.Selvi of Sugarcane Breeding Institute, Coimbatore are thanked for the molecular analysis of hybrids.
REFERENCES


ELARGISSEMENT DE LA BASE GÉNÉTIQUE DE LA CANNE À SUCRE (SACCHARUM SPP.) PAR INTROGRÉSSION DES GÈNES À TRAVERS L’HYBRIDATION INTERGÉNÉRIQUE

Par

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MOTS CLÉS: Erianthus, Nobilisation, Hybride Intergénérique,

Résumé

LA CANNE À SUCRE (Saccharum spp.), est une des cultures chez laquelle l’hybridation interspécifique a fourni des avancées majeures pour son amélioration. Cependant, l’hybridation intergénérique a gagné en importance pour élargir la base génétique et obtenir des traits utiles au niveau industriel et, augmenter la biomasse totale conjointement. Les avantages dérivés de l’utilisation des espèces sauvages comme S. spontaneum ont été réalisés depuis le début des années 1900s. Maintenant, la compatibilité du Saccharum officinarum-Erianthus est explorée pour incorporer les gènes de résistance aux maladies. Le genre a également un grand potentiel pour la vigueur, une meilleure repousse et la tolérance aux stresses environnementaux. Au E.I.D Parry (Inde) Limitée, R & D Centre, des tentatives ont été effectuées à travers un programme d’amélioration conventionnel afin d’introduire ces caractères dans des cultivars commerciaux de canne à sucre. L’authenticité de ces hybrides a été vérifiée sur la base des caractères phénotypiques notamment, l’orientation des feuilles, le dépaillage, la longueur de la tige, le diamètre de la tige, la longueur des entrenœuds, la couleur de la tige et les propriétés biochimiques telles que la teneur en saccharose, la teneur en fibre et des analyses par des techniques moléculaires. Des hybrides intergénériques sélectionnés ont été employés dans des programmes de rétro-croisements pour développer des cultivars commerciaux.
AMPLIANDO LA BASE GENÉTICA DE LA CAÑA DE AZÚCAR (SACCHARUM SPP.) MEDIANTE INTROGRESIÓN DE GENES A TRAVÉS DE LA HIBRIDIZACIÓN INTERGENÉTICA

Por

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PALABRAS CLAVES: Erianthus, Nobilización, Híbridos Intergenéricos.

Resumen

LA CAÑA DE AZÚCAR (Saccharum spp.) es uno de los cultivos en el que mediante la hibridización interespecífica ha proporcionado un importante avance en el mejoramiento de variedades. Sin embargo, la hibridización intergenérica ha ganado importancia para ampliar la base genética y obtener caracteres comerciales útiles y al mismo tiempo incrementar la biomasa. Los beneficios derivados del uso de especies silvestres como S.spontaneum fueron considerados desde los inicios de 1900, y la compatibilidad de Saccharum officinarum con Erianthus se ha explorado para obtener genes de resistencia a enfermedades. Este género también tiene un gran potencial para vigor, mejorar el rebrote y tolerancia al estrés ambiental. En el Centro de Investigaciones E.I.D Parry (India) Ltd., se han realizado varios programas de cruzas convencionales para introducir estos caracteres en los cultivares comerciales. La verdadera naturaleza de estos híbridos se confirman mediante los caracteres morfológicos como orientación de las hojas, rayado de la hoja, largo de tallo, grosor del tallo, largo del entrenudo, color del tallo, y caracteres bioquímicos como contenido azucarero, contenido de fibra y análisis con técnicas moleculares. Los híbridos intergenéricicos son usados como cruzas recurrentes para el desarrollo de cultivares comerciales.
IDENTIFYING QUANTITATIVE TRAIT ALLELES FOR PHYSIOLOGICAL
TRAITS IN SUGARCANE: AN EXPLORATORY STUDY

By

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KEYWORDS: Quantitative Trait, Stalk Elongation, Leaf Appearance,
Photosynthetic Capacity, Crop Model, Phenotypic Variance.

Abstract

This study attempted to shed light on the feasibility of high throughput phenotyping of
physiological traits and the detection of quantitative trait alleles (QTA) for these traits.
Stalk elongation rate per unit thermal time before and after the 14 leaf stage (SER14 and
SER24), leaf appearance rate per unit thermal time (LAR14 and LAR24), fully expanded
leaf area per leaf (LA) and photochemical light use efficiency (P(ABS)) were measured
for 80 clones of a mapping population in three experiments conducted at Mount
Edgecombe, South Africa. Within-experiment clonal repeatability was highly
significant for all traits. Inter-experiment correlations show that SER24, LA and P(ABS)
were reasonably stable across experiments. Significant single marker-trait associations
were found for all traits and multiple marker-trait associations explained from 39% (six
QTAs to predict LAR24) to 55% (five QTAs to predict SER24) of clonal variance.
However, the low number of markers detected in all three experiments cast doubt on the
reliability of marker-based predictions for LAR14, LAR24 and SER24. Results indicate
that LA and P(ABS) were reasonably stable across environments and can be predicted
reliably from genomic information. P(ABS), as estimated through rapid, non-destructive
chlorophyll a fluorescence measurements, in particular shows great promise because it
has the potential for high throughput phenotyping at an early stage in the plant life
cycle. The promising results obtained here suggest that further research is warranted in
refining experimental protocols and validating marker-trait associations in other
germplasm and environments. This could pave the way to explore the exciting
possibilities that gene-to-phenotype modelling offers for enhancing sugarcane breeding.

Introduction

Crop yield is a complex trait governed by numerous dynamic interactions between plant
processes and environment and management factors. Accelerated improvement in plant
performance is only likely when these interactions and the underlying physiological mechanisms
and genetic basis are better understood. Crop simulation models take some of these interactions into
account by simulating the impact of physiological processes such as plant growth rate, leaf
appearance rate, leaf size and photosynthetic capacity. Models therefore have the potential to
identify trait sets that are most likely to enhance yields in target environments (Hammer et al.,
2006).

In parallel, genetics have determined genetic markers or quantitative trait loci (QTL) for
various traits. This information can be used to better understand processes and interactions that
contribute towards yield, and to enhance breeding (Hammer and Jordan, 2007) For sugarcane,
QTLs have been detected for sucrose content (Ming et al., 2001; Aitken et al., 2006; Aitken et al.,
2008), stalk mass and number (Ming et al., 2002; Hoarau et al., 2002; Aitken et al., 2008) and stalk length and stalk diameter (Hoarau et al., 2002; Aitken et al., 2008). These studies all focused on complex yield component traits rather than simple physiological traits related to yield formation processes of resource capture, resource conversion and biomass partitioning. It is believed that despite the genetic influence on yield and its components, there are strong environmental impacts that will make it difficult to detect stable QTLs.

An alternative approach is to define simple, genetically determined, physiological traits and detect stable QTLs for these. Crop models can then be used to simulate the integrated effect of many of these traits in a given environment and thereby identify desirable ones. Sadok et al. (2007) speak of ‘analysing the behaviour of virtual genotypes in silico for large number of environmental scenarios’. Once the ideotype has been identified, the genomic information could be used for rapid screening of genotypes for crossing or selection. Chenu et al. (2008) gave an excellent example of incorporating a QTL based physiological trait module into the APSIM maize model to accurately predict growth of individual leaves and whole crop response to environmental stresses. The model is based on the work by Sadok et al. (2007) and Reymond et al. (2003). They found that maize leaf elongation rate per unit thermal time, when normalised with respect to vapour pressure deficit (VPD) and soil water potential, were genetically determined and that genotype values could be predicted reliably from QTL information.

In sugarcane, it has been shown that stalk elongation rate per unit thermal time is genetically determined to a large extent (Smit and Singels, 2007). There is also evidence that leaf size and leaf elongation rate show large and consistent genotypic variation (Bonnet, 1998; Robertson et al., 1998). However, little genetic and phenotypic information on these traits are available for the wide range of genotypes in existence.

This study attempted to shed light on the feasibility of high throughput phenotyping of physiological traits and the detection of quantitative trait alleles (QTA) for the following physiological traits namely, leaf appearance rate per unit thermal time (LAR), stalk elongation rate per unit thermal time (SER), fully expanded leaf area per leaf (LA), and photochemical light use efficiency (PIABS). These traits were selected based on (1) their importance in determining resource capture and yield formation, (2) the presence of these or similar traits in crop models (3) ability to derive trait values from experimental measurements, and (3) the expected extent of genetic determination.

The specific objectives were to (1) determine the phenotyping repeatability of these traits, (2) identify genetic markers that can be associated with each trait, and (3) determine the reliability of predicting trait values from genetic marker information.

**Methods**

**Mapping population**

A population of 80 sugarcane clones, derived from the South African Sugarcane Research Institute (SASRI) breeding program, were mapped using linkage disequilibrium methods (Butterfield et al., 2008). The map consists of 2054 AFLP and DArT markers arranged on 492 haplotype fragments.

**Experiments**

Three field experiments (T1, T2, T3) were conducted at Mount Edgecombe (29°42’S, 31°03’E) on a sandy clay loam soil covered with a trash blanket to discourage tillering. Plants were adequately fertilised and irrigated. T1 and T2 have been described by Singels et al. (2009). In T1, five setts of each clone were planted in each of four replicates in May 2006. In T2, setts were germinated in vermiculite in a germination chamber at 30°C and transplanted into the field between 29 May and 7 June 2007, when a seedling height of around 10 cm was reached. The number of plants per replicate and number of replicates were the same as in T1. In T3, the germination
chamber and a heated glasshouse were used to manipulate early development of clones to further improve synchronisation of development stage and planting date. Planting in the field took place from 14 to 30 October 2008 and eight setts of each clone were used as individual replicates. In all experiments, secondary tillers were removed as soon as they were visible and only healthy plants were measured.

On a weekly basis, the emergence date of the youngest fully expanded leaf (top visible dewlap (TVD) leaf) was estimated and numbered (starting from the base), and the leaf length and width recorded together with the TVD collar height from ground level. SER for each plant was taken as the slope of the regression of TVD height vs. thermal time. LAR for each plant was taken as the slope of the regression of number of fully expanded leaves vs. thermal time. A distinction was made between the phase between leaf number 8 and 14 (denoted by LAR$_{14}$ or SER$_{14}$), and the phase between leaf number 15 and 24 (denoted by LAR$_{24}$ or SER$_{24}$). Leaf area per leaf (LA) was taken as the average of the fully expanded area (estimated as leaf length x leaf width x 0.71, Sinclair et al., 2004) of leaf number 15 to 24. Due to limited manpower and changes in measurement protocol, the number of plants and replications that were measured for some traits varied.

Photochemical light use efficiency of TVD leaves was only determined in T2 and T3 by recording fast polyphasic chlorophyll $a$ fluorescence transients (Strasser and Govindjee, 1992) at night with a fluorimeter (Plant Efficiency Analyser, Hansatech Instruments Ltd., UK). Four measurements were taken in the mid-section of each TVD leaf on three plants of each clone in each replication (total of 48 measurements per clone). The recorded chlorophyll $a$ fluorescence data were used to calculate the Performance Index (PI$_{ABS}$), which is a sensitive indicator of photosynthetic electron transport efficiency and photosynthetic capacity (Strasser et al., 2000).

Photosynthetic gas exchange measurements were conducted on three clones that represented groups of clones that displayed consistently high, intermediate and low PI$_{ABS}$ values (i.e. high, intermediate and low photochemical light use efficiency). Measurements were conducted with a portable photosynthesis system (Li-Cor 6400, Lincoln, NE, USA) on attached TVD leaves. Measurement of CO$_2$ assimilation rate (A) were taken at incident photon flux (Q) levels of 0, 50, 75, 100, 125, 200, 400, 800, 1500 and 2000 µmol/m$^2$/s provided by an LED light source (LI-6400-02) at an atmospheric CO$_2$ concentration (c$_a$) of 400 µmol/mol. Leaf temperatures in the leaf chamber were maintained at 25ºC and vapour pressure deficits at 1.3 kPa.

Daily maximum and minimum temperature were recorded throughout all three experiments by a nearby automatic weather station and was used to calculate thermal time using a base temperature of 16ºC.

Data analysis

Clonal repeatability (CR – the ratio of genetic variance to phenotypic variance) was determined from an analysis of variance for each experiment separately. The stability of phenotypic measurements was further assessed by determining the correlation between values of a given trait measured in different experiments.

The average value for each trait for each clone in each experiment was calculated from values for individual plants. Data were pooled over experiments by calculating the average of all values over all plants of a given clone. Correlations between traits were determined by comparing the pooled average trait values.

Association between trait values and marker presence or absence was determined for each experiment separately, using the Pearson’s correlation coefficient. A significance level of P=0.05 was chosen. Stepwise linear regression was then used to select markers ascribing maximum phenotypic variation for each trait. This was done using the pooled average trait value for each clone. Selection for markers was limited to those that had significant marker-trait associations in at least two of the three trials. The prediction error (PE) was taken as the standard error of the regression, expressed as a percentage of the observed range in values of each trait.
Responses of A to Q were fitted with the aid of non-linear regressions. The maximum apparent quantum yield of photosynthesis (\(\phi\)) was determined from the linear response of A to Q that persisted between 50 – 400 \(\mu\text{mol/m}^2/\text{s}\) (Long & Hällgren, 1993). The CO\(_2\) assimilation rate at a Q of 2000 \(\mu\text{mol/m}^2/\text{s}\) was regarded as the light saturated rate of CO\(_2\) assimilation (\(A_{\text{sat}}\)). The calculated values of \(\phi\) and \(A_{\text{sat}}\) were used to establish in the three selected clones to what extent differences in photochemical light use efficiency (deduced from PI\(_{\text{ABS}}\) values) translated into differences in overall CO\(_2\) assimilation capacity.

Results

Clonal repeatability

CR was significant (P = 0.001) for all traits in all experiments and exceeded 0.9 in all cases, except for LAR\(_{14}\) in T1 and T2, LAR\(_{24}\) in T2 (Table 1). The range of values is similar to that obtained by Aitken et al. (2008) and Hoarau et al. (2002) for yield component traits. Correlations between trait values from different experiments (Table 2) show that most traits were reasonably stable across experiments, with the exception of LAR\(_{14}\), LAR\(_{24}\) and possibly SER\(_{14}\). These correlations were also generally in the same range than those reported by Aitken et al. (2008). The results suggest that all traits except LAR and possibly SER\(_{14}\) are likely to be genetically determined and can be phenotyped with reasonable accuracy.

<table>
<thead>
<tr>
<th>Trait</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAR(_{14})</td>
<td>0.80</td>
<td>0.65</td>
<td>0.73</td>
</tr>
<tr>
<td>LAR(_{24})</td>
<td>0.90</td>
<td>0.88</td>
<td>0.54</td>
</tr>
<tr>
<td>SER(_{14})</td>
<td>0.95</td>
<td>0.96</td>
<td>0.89</td>
</tr>
<tr>
<td>SER(_{24})</td>
<td>0.93</td>
<td>0.89</td>
<td>0.87</td>
</tr>
<tr>
<td>LA</td>
<td>0.95</td>
<td>0.99</td>
<td>0.95</td>
</tr>
<tr>
<td>PI(_{\text{ABS}})</td>
<td></td>
<td></td>
<td>0.96</td>
</tr>
</tbody>
</table>

Screening of a large number of genotypes for physiological traits will be more useful for breeding programs when the method of phenotyping is quick and can be conducted at an early development stage of the plant. It would be useful, therefore, to determine the correlation between measurements made before leaf stage 14 and thereafter. When trait values were pooled over experiments, significant correlations were found between traits LAR\(_{14}\) and LAR\(_{24}\) (0.645), SER\(_{14}\) and SER\(_{24}\) (0.467), LA\(_{14}\) and LA\(_{24}\) (0.908). It seems that screening for leaf area before leaf stage 14 could be feasible.

Link between CO\(_2\) assimilation capacity and photochemical light use efficiency (PI\(_{\text{ABS}}\))

The extent by which differences in photochemical light use efficiency translated into differences in overall CO\(_2\) assimilation capacity was determined in clones 2, 60 and 79. These clones had PI\(_{\text{ABS}}\) values that were respectively 49% and 0.5% higher and 43% lower than the average PI\(_{\text{ABS}}\) value for all 80 clones, thus representing high, intermediate and low PI\(_{\text{ABS}}\). This analysis revealed that values
for $A_{sat}$ and $\phi$ corresponded with the relative positions of the three clones according to $PI_{ABS}$. For example, clone 2 (highest $PI_{ABS}$) had $A_{sat}$ and $\phi$ values respectively 39% and 52% higher than in clone 79 (lowest $PI_{ABS}$), while clone 60 (intermediate $PI_{ABS}$) had values respectively 20% and 14% higher than in clone 79.

**Marker-trait associations**

The phenotypic variation accounted for by genetic markers and the reliability of marker-based predictions are given in Table 3. The number of markers detected in all three experiments was considerably lower than the number detected in any two experiments, especially for traits $LAR_{14}$, $LAR_{24}$, $SER_{24}$, suggesting that some of these detections may be false. These results highlight the necessity of multi-experiments for true marker detection and for the need for more precise phenotyping.

The multiple marker-trait associations determined for all traits were promising, with $R^2$ values 0.4 or more, and PE values of 15% or less. The strongest single marker-trait associations explained between 14.3 and 25.3% of the phenotypic variance, which compares well with values reported by Aitken *et al.* (2008) and Aitken *et al.* (2006).

**Table 3**—Number of markers with significant correlations with trait values in all three experiments, in two out of three experiments and the highest number of markers detected in any one experiment; the number of markers selected in the stepwise multiple regression to predict the trait value, the coefficient of determination for the regression, the highest and lowest $R^2$ contribution from individual markers to the regression, and the prediction error (PE) between predicted and observed trait values.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Single marker-trait associations</th>
<th>Multiple marker-trait associations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Markers detected in 3 exp</td>
<td>Markers detected in 2 exp</td>
</tr>
<tr>
<td>$LAR_{14}$</td>
<td>4</td>
<td>42</td>
</tr>
<tr>
<td>$LAR_{24}$</td>
<td>1</td>
<td>48</td>
</tr>
<tr>
<td>$SER_{14}$</td>
<td>29</td>
<td>123</td>
</tr>
<tr>
<td>$SER_{24}$</td>
<td>7</td>
<td>56</td>
</tr>
<tr>
<td>LA</td>
<td>63</td>
<td>144</td>
</tr>
<tr>
<td>$PI_{ABS}$</td>
<td>57</td>
<td>165</td>
</tr>
</tbody>
</table>

**Discussion**

Results suggest that LA and $PI_{ABS}$ are reasonably stable across environments and can be predicted reliably from genomic information. $PI_{ABS}$, as estimated through rapid, non-destructive chlorophyll $a$ fluorescence measurements, in particular shows great promise because it has the potential for high throughput phenotyping at an early stage in the plant life cycle. At least in the three clones on which detailed measurements of CO$_2$ assimilation capacity were conducted, a strong agreement between photochemical light use efficiency and overall CO$_2$ assimilation capacity (which is most probably an important contributor to high biomass and sucrose yields) was clearly demonstrated.

Observations of stalk elongation and leaf appearance traits were not that repeatable and marker-based predictions were not sufficiently reliable. Possible reasons could be inappropriate sampling techniques or problems with experimental procedures. For example, it was very difficult to synchronise all clones to reach the same developmental stage at the same time. In T2 and T3, germinating setts were initially exposed to artificial environments for different time periods to achieve this. Pests (monkeys, thrips) and disease (pokka boeng) also affected some plants.

Unreliable marker-based predictions could also be due to insufficient separation of genetic and environmental aspects in the trait definition. For example, Robertson *et al.* (1998) found that
temperature affected LA and Smit and Singels (2007) found that genetic control of SER was confounded by site and season effects. Reymond et al. (2003) showed that SER in maize was controlled by soil water potential and atmospheric VPD. In our study, we tried to eliminate soil water status as a source of variation. The impact of VPD on observed SER still needs to be investigated.

The promising results obtained here suggest that further research is warranted in refining experimental protocols and validating marker-trait associations in other germplasm and environments. This could pave the way to explore the exiting possibilities that gene-to-phenotype modelling offers for enhancing sugarcane breeding.

Acknowledgements

We gratefully acknowledge the contributions by SASRI technicians and interns (experimental data collection) and Chandani Sewpersad (data analysis of T3).

REFERENCES


IDENTIFICATION DES ALLÈLES À EFFET QUANTITATIF POUR DES CARACTÈRES PHYSIOLOGIQUES DE LA CANNE À SUCRE: UNE ÉTUDE EXPLORATOIRE

Par

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MOTS CLÉS: Trait Quantitatif, Élongation de la Tige,
Apparition de la Feuille, Capacité de Photosynthèse,
Modèle de Croissance, Variance Phénotypique.

Résumé
CETTE ÉTUDE explore les possibilités du déterminisme phénotypique haut débit des caractères physiologiques et la détection des allèles à effet quantitatif (QTA) pour ces traits. Le taux d’élongation des tiges par unité thermale de temps avant et après le stade 14-feuille (SER14 et SER24), la vitesse d’apparition de la feuille par unité thermale de temps (LAR14 et LAR24), l’expansion totale de la surface foliaire (LA) et l’efficience de l’utilisation photochimique (PIABS) ont été mesurés sur 80 clones caractérisés moléculairement à partir de trois essais à Mount Edgecombe, Afrique du Sud. La répétitivité clonale intra-essai était hautement significative pour tous les traits. Les corrélations inter-expérimentation ont montré que SER24, LA et PIABS étaient raisonnablement stables à travers les expérimentations. Des associations significatives de marqueurs-trait simples étaient observées pour tous les caractères alors que les associations des marqueurs-multiples expliquent entre 39% (six QTAs pour prédire LAR24) à 55% (cinq QTAs pour prédire SER24) de la variance clonale. Cependant, le nombre restreint de marqueurs détectés dans les trois expérimentations émet des doutes quant à la fiabilité des prédictions basées sur les marqueurs associés à LAR14, LAR24 et SER24. Les résultats indiquent que LA et PIABS sont raisonnablement stables à travers les environnements et peuvent être prédites avec fiabilité à partir de l’information génomique. La PIABS, estimée à partir des mesures rapides et non-destructives de fluorescence de chlorophylle a, est prometteuse en particulier car elle démontre un potentiel pour le phénotypage à haut débit à un stade précoce du cycle de la plante. Les résultats prometteurs obtenus suggèrent que davantage de recherche est nécessaire pour raffiner les protocoles expérimentaux et valider les associations marqueurs-trait chez d’autres sources de germoplasme et dans d’autres environnements. Ceci pourrait préparer le terrain pour une exploration des possibilités excitantes qu’offre la modélisation gène-phénotype dans l’amélioration de la canne à sucre.
IDENTIFICANDO ALELOS CUANTITATIVOS PARA CARACTERES FISIOLÓGICOS EN CAÑA DE AZÚCAR: UN ESTUDIO EXPLORATORIO

Por

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PALABRAS CLAVE: Caracteres Cuantitativos, Alargamiento del Tallo, Apariencia de Hoja, Capacidad Fotosintética, Variación Fototípica.

Resumen

Este estudio ha intentado clarificar sobre la posibilidad de un sistema eficiente de determinación de caracteres fenotípicos fisiológicos y su detección de alelos de caracteres cuantitativos (QTA). La tasa de alargamiento del tallo por unidad de tiempo termal antes y después de la hoja 14 (SER14 y SER 24), apariencia de la hoja por unidad de tiempo termal (LAR 14 y LAR 24), área de la hoja expandida totalmente por hoja (LA) y eficiencia fotoquímica en el uso de la luz (PIABS) se midieron en 80 clones de las poblaciones en mapeo en tres experimentos realizados en Mount Edgecombe, Sur África. La repetitividad clonal dentro de los experimentos fue altamente significativa para todos los caracteres. Las correlaciones entre experimentos mostraron que SER24, LA y PIABS fueron razonablemente estables a lo largo de los experimentos. La asociación simple entre carácter-marca dor fue significativa para todos los caracteres y la asociación múltiple entre marcador-carácter se explica desde 39% (seis QTAs para predecir LAR24) a 55% de la variación clonal (cinco QTAs para predecir SER24). Sin embargo, el bajo número de marcadores detectados en los tres experimentos dejan dudas en la relatividad de las predicciones basadas en marcadores para LAR14, LAR24 and SER24. Los resultados indican que LA y PIABS fueron razonablemente estables en los experimentos y se puede predecir con confianza desde la información genética. El PIABS, como un estimado rápido, de medida de la clorofila a mediante fluorescencia, en particular, se muestra promisorio para clasificar fenotípicamente en estados tempranos del ciclo de vida de la planta. Estos resultados promisorios obtenidos aquí sugieren que se justifican otros estudios para que garanticen los protocolos experimentales y la validación de la asociación marcador-carácter en otros germoplasmas y ambientes. Esto podría preparar el terreno para explorar la posibilidad de que modelos existentes gen-a-genotipo ayuden a fortalecer los programas de mejora genética.
USE OF HISTORICAL MULTI-LOCATION SUGAR CANE VARIETY TRIALS DATA TO IDENTIFY RELATIONSHIPS AMONG ENVIRONMENTS IN TERMS OF GENOTYPE RESPONSES

By

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KEYWORDS: AMMI, Cane Yield (TCH), Genotype × Environment Interaction, Genotype Responses, Multi-Location Trials, PCA.

Abstract

In Mauritius, sugarcane is grown over diverse environments that can be grouped into three main zones: the Superhumid, Humid and Subhumid. In each zone, multi-location variety trials are established with several genotypes to provide reliable information for identifying high yielding varieties. Genotype × Environment (G × E) interaction is the major complicating element in selecting genotypes suitable for commercial production. However, one of the difficult aspects of conducting trials in several environments is the choice of test sites. It is important to plan a rational variety-testing program with confidence. Available historical data were used from four series of final phase trials established in different years to study the main effects environment (E) and genotype (G) as well as G× E interactions. The aim was to identify relationships among test sites in terms of genotype responses and to assess the extent to which environments were similar or different. Cumulative results of a plant crop and three ratoon crops for cane yield (TCH) were analysed. In the superhumid zone, located at high elevation, G× E interaction was not important within the rocky (B) and the deep free (F) soils. In contrast, a significant G× E interaction was observed within B and F soils for locations lying in relatively higher and lower elevations in different sectors. Similarly, among locations in the Humic Latosols (H2) soils and between H2 and L2 soils, interaction was not prominent. Furthermore, the B, F and H soils were found to be the cause of different genetic responses. In the subhumid zone, a highly significant G× E interaction was found between all the Low Humic Latosols (L1, L2) and the Latosolic Reddish Prairie soils (P2 and P3). The study confirmed that trials should be established in B, F, L and P soils mainly but should be replicated within the B and F soils prevailing in the different sectors of the island.

Introduction

In Mauritius, sugarcane is grown over diverse agro-climatic environments that are grouped into three main environments, the Superhumid, Humid and Subhumid zones, and five main soil types. The Superhumid zone, with an annual rainfall of >2400 mm, comprises three main soil types: the Latosolic Brown Forest (B1 and B2) that are rocky intrazonal soils very high in organic matter, have evolved on the late lavas and are strongly to slightly acidic; the Humic Ferruginous Latosols (F1, F2 and F3) are deep free zonal soils high in organic matter, and have developed from the early and intermediate lavas and are strongly to medium acidic; the Humic Latosols (H) soils, which have developed on the intermediate lavas (Parish and Feillafé, 1965).

The Humid zone (1800 mm to 2400 mm) are deep fertile soils that include mostly the Low Humic Latosols (L2) soils, have developed on the intermediate lavas and are medium to slightly acidic.
The Subhumid zone, with mean annual rainfall <1800mm, comprises the Low Humic Latosols (L1, L3 and L4) soils, which are deep soils low in organic matter with good internal drainage developed from the intermediate lavas, and the Latosolic Reddish Prairie (P1, P2 and P3) soils developed from the late lavas below the 2500mm isohyets, which are high in organic matter. Parish and Feillafé (1965) have reported that the whole solum contains varying amounts of cobbles and gravels of unweathered or slightly weathered basalt, and bedrock exposures are common. The P1 and P2 soils are mainly shallow and gravelly whereas most of the P3 soils are very rocky. The soils in the subhumid zone are neutral to slightly acidic.

The percentage area under sugarcane cultivation in the B, F, H, L and P soils in different rainfall ranges across the island are shown in Table 1 below. The B, F and H2 soils of the superhumid zone occupy about 33% of the total area under cultivation, the L2 soil of the humid zone constitutes about 10% of the total area; whereas, for the L1 and P soils in the subhumid zone, the percentage area under cultivation is about 29%.

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Rainfall range</th>
<th>% Area under sugarcane</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>2400–3000</td>
<td>5.8</td>
</tr>
<tr>
<td></td>
<td>&gt;3000</td>
<td>8.2</td>
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<tr>
<td>F</td>
<td>2400–3000</td>
<td>6.4</td>
</tr>
<tr>
<td></td>
<td>&gt;3000</td>
<td>7.0</td>
</tr>
<tr>
<td>H2</td>
<td>2400–3000</td>
<td>5.4</td>
</tr>
<tr>
<td></td>
<td>&gt;3000</td>
<td>0.7</td>
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<tr>
<td>L1</td>
<td>0–1800</td>
<td>7.7</td>
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<td>L2</td>
<td>1800–2400</td>
<td>10.0</td>
</tr>
<tr>
<td>P1/P2</td>
<td>0–1800</td>
<td>12.8</td>
</tr>
<tr>
<td>P3</td>
<td>0–1800</td>
<td>8.4</td>
</tr>
</tbody>
</table>

The breeding and selection program of the Mauritius Sugar Industry Research Institute (MSIRI) currently extends over 11 to 15 years from the time of sowing to the release of a new sugarcane variety. The program includes a preliminary phase of selection comprising a seedling and three clonal stages and a final phase that consists of two stages. At the final phase, about 60 to 80 promising genotypes selected from the third clonal stage of the preliminary phase, are tested in two or more series of trials established in four main soil types B, F, L2 and P1/P2 (Irrigated) throughout the island and harvested at mid-season (mid-August to mid-October).

The second stage (T2) consists of one or more series of trials planted in five complementary soil types to T1, in B, F, H, L1 (irrigated) and P3 or P1/P2 or L1 (non-irrigated), which are harvested early (June to mid-August) and/or late (end October/November) in the season. The number of the sites selected also depends on the availability of land, planting material and human resources. Promising genotypes are evaluated in a wide range of environments and their performance is influenced by the genotype×environment interactions. The magnitude of these interactions determines whether the genotype is adapted to a specific environment, a group of similar environments or to a wide range of environments.

Historical data available in the plant breeding databases was used to study the main effects environment (E) and genotype (G) as well as the G×E interactions in a series of trials established over several years. The aim of this study was to identify relationships among test locations in terms of genotype responses in order to assess the extent of similarities or differences among environments. The results would provide useful information in the choice of testing sites at the final phase of the selection program.
Materials and methods

Availability of reliable data on common genotypes planted in different environments is the main prerequisite of this study. In this respect, the historical data were explored and four series of trials planted at the final phase of testing were considered as per Table 2 below.

Table 2—Multi-location trials harvested at mid-season.

<table>
<thead>
<tr>
<th>Series</th>
<th>Estates</th>
<th>Sections</th>
<th>Sector</th>
<th>Soil types</th>
<th>Irrigation</th>
<th>Rainfall (mm)</th>
<th>Altitude (m)</th>
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<td>1979</td>
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<td>Valetta</td>
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<td>3302</td>
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<tr>
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<td>Fuel</td>
<td>Bel Etang</td>
<td>East</td>
<td>B1</td>
<td>Nil</td>
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<td>265</td>
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<td>Rose Belle</td>
<td>Eau Bleu</td>
<td>South</td>
<td>F1</td>
<td>Nil</td>
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<td>1979</td>
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<td>Mon Vernon</td>
<td>South</td>
<td>F1</td>
<td>Nil</td>
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<td>Richemond</td>
<td>South</td>
<td>H</td>
<td>Nil</td>
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<td>Mauricia</td>
<td>North</td>
<td>L1</td>
<td>Nil</td>
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<td>Esperance</td>
<td>North</td>
<td>L1</td>
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<td>Olivia</td>
<td>East</td>
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<td>Mon Rocher</td>
<td>North</td>
<td>P3</td>
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<td>Médine</td>
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</table>

The first series (Table 2) consisted of trials established in twelve environments in 1979 and harvested at mid-season. The trial design at each site was an RCB with four replications. The same twelve varieties were tested at all sites during 4 years in the plant cane and three ratoon crops. Five of the twelve trials were situated in the superhumid zone, two in the Latosolic Brown Forest soils (B1), two in the Humic Ferruginous Latosol soils (F1) and one in the Humic Latosol soils (H). Six trials were located in the subhumid zone with three trials in the Low Humic Latosol soils (L1 & L2) and three in the Latosolic Reddish Prairie soils (P2 & P3). One trial in the P3 soil was situated in a humid zone.
The second series (Table 2) consisted of ten trials with RCB designs and four replications. The same ten varieties were tested at all sites during 4 years in the plant cane and three ratoon crops. Two trials were planted in each of the B1, H2, L1, L2, and one trial in P2 and P3 soils respectively.

The third series (Table 2) consisted of ten trials with RCB designs and four replications. Ten varieties were tested at all sites during 4 years in the plant cane and three ratoon crops. Two trials were planted in each of the B1, F1, H2, L2 and P3 soils respectively.

The fourth series (Table 2) consisted of eleven trials with lattice designs and three replications. Twenty varieties were used in the trials and five of these were tested at all sites during 4 years in the plant cane and three ratoon crops. In the superhumid zone, three trials were planted in the B1 soils and four in the F1 soils whereas one trial was established in the L1, L2, P1 and P2 soils respectively.

The experimental plots of all the trials consisted of four rows each of 10 m spaced at 1.5 m with pathways 1.0 m wide between blocks of plots.

Statistical analyses

The G×E interaction was partitioned into a number of components of variance by making use of the Additive Main effects and Multiplicative Interaction model (AMMI). The classical analysis of variance constitutes the additive part of the ANOVA model and is used to compute the genotype and environment additive effects. The principal component analysis (PCA) is then used to analyse non-additive interaction effects.

The AMMI models (Gauch, 1987) were fitted to the data of the different series of trials to determine the Genotype×Environment interaction. The model for T genotypes and S environments is given as:

\[
Y_{ij} = \mu + g_i + e_j + \sum_{n=1}^{n'} \lambda_n \alpha_{inj} + \gamma_{jn} + \phi_{ij}
\]

where \(Y_{ij}\) is the mean yield of \(i^{th}\) genotype in the \(j^{th}\) environment; \(\mu\) is the general mean; \(g_i\) is the \(i^{th}\) genotypic effect; \(e_j\) is the \(j^{th}\) environment effect; \(\lambda_n\) is the eigen value of the PCA axis \(n\); \(\alpha_{inj}\) and \(\gamma_{jn}\) are the \(i^{th}\) genotype \(j^{th}\) environment PCA scores for the PCA axis \(n\); \(\phi_{ij}\) is the residual; \(n'\) is the number of PCA axes retained in the model.

One requirement of the AMMI model is that the matrix of means should be larger than \(3 \times 3\), requiring more than 3 genotypes to be tested in 3 or more environments (Gauch and Zobel, 1989). Hence, in cases when the number of trials was less than three, the classical analysis of variance with the following model was used:

\[
Y_{ij} = \mu + g_i + e_j + g_i e_j + \epsilon
\]

where \(\mu\) is the general mean; \(g_i\) is the \(i^{th}\) genotypic effect; \(e_j\) is the \(j^{th}\) environment effect; \(g_i e_j\) is the interaction effect and \(\epsilon\)’s denote the random errors.

The two middle experimental rows of each plot were harvested and the plot weight for each variety recorded to determine the cane yield per hectare (TCH) for the first, second and third ratoon crops.

Statistical analysis was performed on the cumulative data of the 1st, 2nd and 3rd ratoon crops using Genstat for windows (Release 11.1) for each environment within series of trials and the residual errors were used for tests of significance after pooling.
Results and discussion

The results are summarised in Tables 3 and 4 for the superhumid zone and Tables 5 and 6 for the subhumid zone.

The superhumid zone

Table 3—F values with significance levels from AMMI/Classical ANOVA models for Environment, Genotype and G×E interactions for cane yield in the B, F and H soils of the superhumid zone.

<table>
<thead>
<tr>
<th>Year</th>
<th>Soils</th>
<th>Environment</th>
<th>Genotype</th>
<th>G×E interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>df TCH</td>
<td>df TCH</td>
<td>df TCH</td>
</tr>
<tr>
<td>1979</td>
<td>B</td>
<td>1 7.42**</td>
<td>11 11.78***</td>
<td>11 1.75ns</td>
</tr>
<tr>
<td>1982</td>
<td>1.98ns</td>
<td>6 2.02ns</td>
<td>6 0.27ns</td>
<td></td>
</tr>
<tr>
<td>1984</td>
<td>2.4ns</td>
<td>8 14.81***</td>
<td>8 2.47*</td>
<td></td>
</tr>
<tr>
<td>1993</td>
<td>2</td>
<td>212.76***</td>
<td>4 25.51***</td>
<td>8 3.3*</td>
</tr>
<tr>
<td>1979</td>
<td>F</td>
<td>1 206.07***</td>
<td>11 6.04***</td>
<td>11 1.76ns</td>
</tr>
<tr>
<td>1984</td>
<td>1</td>
<td>4.15*</td>
<td>8 19.49***</td>
<td>8 9.13***</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>3.81*</td>
<td>4 7.41***</td>
<td>12 7.05***</td>
</tr>
<tr>
<td>1982</td>
<td>H2</td>
<td>1 290.22***</td>
<td>6 26.97***</td>
<td>6 1.78ns</td>
</tr>
<tr>
<td>1984</td>
<td>13.45***</td>
<td>10 16.16***</td>
<td>8 1.39ns</td>
<td></td>
</tr>
<tr>
<td>1979</td>
<td>B &amp; F</td>
<td>3 17.87***</td>
<td>11 22.77***</td>
<td>33 2.31**</td>
</tr>
<tr>
<td>1984</td>
<td>0.84ns</td>
<td>8 35.43***</td>
<td>24 6.19***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>7.95***</td>
<td>4 72.22***</td>
<td>24 10.74***</td>
</tr>
<tr>
<td>1984</td>
<td>3</td>
<td>14.97***</td>
<td>8 27.82***</td>
<td>24 2.58**</td>
</tr>
<tr>
<td>1979</td>
<td>F &amp; H</td>
<td>2 24.86***</td>
<td>11 10.51***</td>
<td>22 2.43**</td>
</tr>
<tr>
<td>1984</td>
<td>3</td>
<td>19.43***</td>
<td>8 22.45***</td>
<td>24 6.46***</td>
</tr>
</tbody>
</table>

ns: not significant; *: significant at 5%; **: significant at 1%; ***: significant at 0.1%.

Table 4—Contribution of each source of variation expressed as % of sum of squares (SS) for cane yield across the different environments (B, F and H soils) in the superhumid zone.

<table>
<thead>
<tr>
<th>Year</th>
<th>Soils</th>
<th>Environment</th>
<th>Genotype</th>
<th>G×E Interaction</th>
<th>Ratio GxE/G</th>
<th>Ratio GxE/E</th>
</tr>
</thead>
<tbody>
<tr>
<td>1979</td>
<td>B</td>
<td>3.1</td>
<td>54.0</td>
<td>8.2</td>
<td>0.15</td>
<td>2.65</td>
</tr>
<tr>
<td>1982</td>
<td>3.3</td>
<td>19.9</td>
<td>2.7</td>
<td>0.14</td>
<td>0.82</td>
<td></td>
</tr>
<tr>
<td>1984</td>
<td>1.23</td>
<td>61.0</td>
<td>10.2</td>
<td>0.17</td>
<td>8.29</td>
<td></td>
</tr>
<tr>
<td>1993</td>
<td>34.8</td>
<td>43.3</td>
<td>11.2</td>
<td>0.26</td>
<td>0.32</td>
<td></td>
</tr>
<tr>
<td>1979</td>
<td>F</td>
<td>5.5</td>
<td>17.6</td>
<td>5.2</td>
<td>0.30</td>
<td>0.95</td>
</tr>
<tr>
<td>1984</td>
<td>1</td>
<td>49.9</td>
<td>23.4</td>
<td>0.47</td>
<td>18.00</td>
<td></td>
</tr>
<tr>
<td>1993</td>
<td>30.8</td>
<td>11.9</td>
<td>74.0</td>
<td>6.22</td>
<td>2.40</td>
<td></td>
</tr>
<tr>
<td>1982</td>
<td>H2</td>
<td>57.4</td>
<td>32.0</td>
<td>2.1</td>
<td>0.07</td>
<td>0.04</td>
</tr>
<tr>
<td>1984</td>
<td>8.2</td>
<td>49.7</td>
<td>6.8</td>
<td>0.14</td>
<td>0.83</td>
<td></td>
</tr>
<tr>
<td>1979</td>
<td>B &amp; F</td>
<td>39.3</td>
<td>27.5</td>
<td>54.7</td>
<td>1.99</td>
<td>1.39</td>
</tr>
<tr>
<td>1984</td>
<td>2</td>
<td>50.5</td>
<td>52.5</td>
<td>1.04</td>
<td>26.25</td>
<td></td>
</tr>
<tr>
<td>1993</td>
<td>36.6</td>
<td>17.2</td>
<td>76.4</td>
<td>4.44</td>
<td>2.09</td>
<td></td>
</tr>
<tr>
<td>1982</td>
<td>B &amp; H</td>
<td>45.3</td>
<td>22.1</td>
<td>75.9</td>
<td>3.43</td>
<td>1.68</td>
</tr>
<tr>
<td>1984</td>
<td>25.8</td>
<td>40.9</td>
<td>54.0</td>
<td>1.32</td>
<td>2.09</td>
<td></td>
</tr>
<tr>
<td>1979</td>
<td>F &amp; H</td>
<td>40.6</td>
<td>24.3</td>
<td>87.0</td>
<td>3.58</td>
<td>2.14</td>
</tr>
<tr>
<td>1984</td>
<td>34.0</td>
<td>27.7</td>
<td>60.4</td>
<td>2.18</td>
<td>1.78</td>
<td></td>
</tr>
</tbody>
</table>

In the superhumid zone, a significant G×E interaction was observed between the B & F soils as well as between the B & H and F & H soils for the character cane yield (Table 3), indicating that the performance of the genotypes was different in these environments. Highly significant differences were detected among genotypes and environments. The genotypes SS (11.9%–61.0%)
contributed more to the total SS than the environments SS (1.23%–57.4%) for the character evaluated (Table 4). The ratio G×E interaction SS to the main effect for environment represented a relatively higher percentage than that of the main effect for genotype.

Within the B soils, results from the two series of trials (1984 and 1993), showed that the G×E interaction was significant whereas results from the other two series (1979 and 1982) did not show any significant G×E interaction (Table 3). This can be due to the fact that in 1984 and 1993 the trials were established in different parts of the island under quite different climatic conditions in terms of altitude and annual rainfall (Table 2) whereas, in 1979 and 1982, the trials were established at higher elevation with higher rainfall compared to the other two year series. It appears that within the B soils, the presence of different agroclimatic conditions may lead to inconsistent performance of the genotypes, which indicates that more than one trial should be established in this type of soil, in the South and in the Centre/Eastern part of the island.

Within the H soils, the trials established at different locations and under quite similar agroclimatic conditions in the east and south of the island (Table 2) did not show any significant G×E interaction (Table 3). Only one trial can be planted either in the east or in the south of the island in the H soils.

Within the F soils (Table 3), no significant G×E interaction was found for the trials planted in 1979 in the south of the island with high rainfall. However, the results from trials planted in 1984 (Table 2) at high altitude in the south and centre of the island with relatively different mean annual rainfall showed a significant G×E interaction. The trials established in 1993 in the east, south and centre of the island at different altitude and rainfall also indicated a significant G×E interaction. The results imply that the genotypes need to be tested in more than one location in the F soils in the South and the Centre/East.

In some cases, classical ANOVA did not detect any significant interaction whereas the AMMI analysis revealed a significant interaction confirming the accuracy of the AMMI model as also reported by Gauch Jr. et al. (1988), Srivastava et al. (1999) and Bissessur et al. (2001).

The subhumid zone

Table 5–F values with significance levels from AMMI/Classical ANOVA models for Environment, Genotype and G×E interactions for cane yield in the L and P soils of the subhumid zone.

<table>
<thead>
<tr>
<th>Year</th>
<th>Soils</th>
<th>Environment df</th>
<th>TCH</th>
<th>Genotype df</th>
<th>TCH</th>
<th>G×E interaction df</th>
<th>TCH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1979</td>
<td>L1</td>
<td>1</td>
<td>75.84***</td>
<td>11</td>
<td>5.64***</td>
<td>11</td>
<td>2.32*</td>
</tr>
<tr>
<td></td>
<td>P2</td>
<td>1</td>
<td>0.05ns</td>
<td>11</td>
<td>5.33***</td>
<td>11</td>
<td>2.64**</td>
</tr>
<tr>
<td></td>
<td>L1 &amp; L2</td>
<td>2</td>
<td>132.2***</td>
<td>11</td>
<td>6.7***</td>
<td>22</td>
<td>3.2***</td>
</tr>
<tr>
<td></td>
<td>L1 &amp; P2</td>
<td>3</td>
<td>7.83***</td>
<td>11</td>
<td>8.79***</td>
<td>33</td>
<td>3.39***</td>
</tr>
<tr>
<td></td>
<td>L1 &amp; P3</td>
<td>3</td>
<td>190.43***</td>
<td>11</td>
<td>3.94***</td>
<td>33</td>
<td>1.91**</td>
</tr>
<tr>
<td></td>
<td>L2 &amp; P2</td>
<td>2</td>
<td>15.1**</td>
<td>11</td>
<td>8.03***</td>
<td>22</td>
<td>2.5***</td>
</tr>
<tr>
<td></td>
<td>L2 &amp; P3</td>
<td>2</td>
<td>202.36***</td>
<td>11</td>
<td>4.57***</td>
<td>22</td>
<td>1.88**</td>
</tr>
<tr>
<td></td>
<td>L2 &amp; H2</td>
<td>1</td>
<td>35.05***</td>
<td>11</td>
<td>7.82***</td>
<td>11</td>
<td>1.55ns</td>
</tr>
<tr>
<td></td>
<td>P2 &amp; P3</td>
<td>1</td>
<td>28.87***</td>
<td>4</td>
<td>6.36***</td>
<td>4</td>
<td>2.4**</td>
</tr>
<tr>
<td>1982</td>
<td>L1</td>
<td>1</td>
<td>8.90**</td>
<td>7</td>
<td>10.31***</td>
<td>7</td>
<td>1.17ns</td>
</tr>
<tr>
<td></td>
<td>L2</td>
<td>1</td>
<td>9.97***</td>
<td>7</td>
<td>15.9***</td>
<td>7</td>
<td>0.65ns</td>
</tr>
<tr>
<td></td>
<td>L1 &amp; L2</td>
<td>3</td>
<td>3.05**</td>
<td>7</td>
<td>31.65**</td>
<td>21</td>
<td>1.71*</td>
</tr>
<tr>
<td></td>
<td>L2 &amp; H2</td>
<td>3</td>
<td>115.19***</td>
<td>9</td>
<td>28.55***</td>
<td>17</td>
<td>1.35ns</td>
</tr>
<tr>
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<td>L2</td>
<td>1</td>
<td>16.52***</td>
<td>8</td>
<td>15.03***</td>
<td>8</td>
<td>2.09ns</td>
</tr>
<tr>
<td></td>
<td>P3</td>
<td>1</td>
<td>47.52***</td>
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<td>6.59***</td>
<td>8</td>
<td>2.66*</td>
</tr>
<tr>
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<td>L2 &amp; P3</td>
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<td>73.3***</td>
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<td>18.07***</td>
<td>24</td>
<td>2.68**</td>
</tr>
<tr>
<td></td>
<td>L2 &amp; H2</td>
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<td>17.44***</td>
<td>9</td>
<td>20.17***</td>
<td>23</td>
<td>1.52ns</td>
</tr>
</tbody>
</table>

ns: not significant; *: significant at 5%; **: significant at 1%; ***: significant at 0.1%
Table 6–Contribution of each source of variation expressed as % sum of squares (SS) for cane yield across the different environments (L and P soils) in the Subhumid zone

<table>
<thead>
<tr>
<th>Year</th>
<th>Soils</th>
<th>Environment</th>
<th>Genotype</th>
<th>G×E interaction</th>
<th>Ratio GxE/G</th>
<th>Ratio GxE/E</th>
</tr>
</thead>
<tbody>
<tr>
<td>1979</td>
<td>L1</td>
<td>28.8</td>
<td>23.6</td>
<td>9.7</td>
<td>0.41</td>
<td>0.34</td>
</tr>
<tr>
<td></td>
<td>P2</td>
<td>0.03</td>
<td>34.9</td>
<td>17.3</td>
<td>0.50</td>
<td>576.67</td>
</tr>
<tr>
<td></td>
<td>L1 &amp; L2</td>
<td>51.2</td>
<td>14.2</td>
<td>10.7</td>
<td>0.75</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>L1 &amp; P2</td>
<td>25.5</td>
<td>17.4</td>
<td>9.6</td>
<td>0.55</td>
<td>0.38</td>
</tr>
<tr>
<td></td>
<td>L1 &amp; P3</td>
<td>67.4</td>
<td>5.1</td>
<td>7.6</td>
<td>1.49</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>L2 &amp; P2</td>
<td>10.7</td>
<td>31.3</td>
<td>14.1</td>
<td>0.45</td>
<td>1.32</td>
</tr>
<tr>
<td></td>
<td>L2 &amp; P3</td>
<td>66.3</td>
<td>8.2</td>
<td>6.8</td>
<td>0.83</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>L2 &amp; H2</td>
<td>16.9</td>
<td>41.4</td>
<td>8.2</td>
<td>0.20</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>P2 &amp; P3</td>
<td>57.2</td>
<td>8.7</td>
<td>9.9</td>
<td>1.14</td>
<td>0.17</td>
</tr>
<tr>
<td>1982</td>
<td>L2</td>
<td>5.7</td>
<td>6.4</td>
<td>2.6</td>
<td>0.46</td>
<td>0.41</td>
</tr>
<tr>
<td></td>
<td>L1</td>
<td>6.3</td>
<td>51.4</td>
<td>5.8</td>
<td>0.11</td>
<td>0.92</td>
</tr>
<tr>
<td></td>
<td>L1 &amp; L2</td>
<td>8.2</td>
<td>52.6</td>
<td>8.6</td>
<td>0.16</td>
<td>1.05</td>
</tr>
<tr>
<td></td>
<td>L2 &amp; H2</td>
<td>48.0</td>
<td>35.7</td>
<td>0.03</td>
<td>0.0008</td>
<td>0.0006</td>
</tr>
<tr>
<td>1984</td>
<td>L2</td>
<td>8.0</td>
<td>58.2</td>
<td>8.1</td>
<td>1.14</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>P3</td>
<td>27.2</td>
<td>30.2</td>
<td>12.2</td>
<td>0.40</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>L2 &amp; P3</td>
<td>46.8</td>
<td>24.8</td>
<td>9</td>
<td>0.36</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>L2 &amp; H2</td>
<td>13.9</td>
<td>48.1</td>
<td>9.2</td>
<td>0.20</td>
<td>0.66</td>
</tr>
</tbody>
</table>

In the subhumid zone, a significant G×E interaction was observed within L1, P2 and P3 soils, and between L1 & L2, L2 & P3, P2 & P3, L1 & P2, L1 & P3, L2 & P2 soils (Table 5). However, no significant interaction was observed within the L2 soils as well as between L2 and H2 soils. The results indicated that it was necessary to establish trials in each of the L and P soils of the subhumid zone but there is no need to replicate trials in L2 and H2 soils. The genotypes SS contributed about 5.1% to 58.2% to the total SS whereas the environments SS contributed about 0.03% to 67.4% and the interaction SS contributed about 0.03 to 17.3% for the character evaluated (Table 6).

In the P2 and P3 soils the genotype SS (34.9% and 30.2%) contributed relatively more to the total SS than the environment SS (0.03% and 27.2%). The ratio G×E interaction SS to the main effect for genotype represented a slightly higher percentage than that of the main effect for environment. The results highlighted the importance of G×E interaction and justified the necessity of establishing more trials in the subhumid zone, particularly in the L1 and P soils whereas replication of trials in L2 and H2 soils was not necessary.

These results confirm the current practice of establishing trials in each soil type, and trials in H2 soils can be considered as complementary to trials in L2 soils. They also confirm the inconsistent performance of some commercial varieties in B and F soils that prevail in different sectors of the island. The current practice of implementing a second series of trials in soil groups in different sectors of the island is fully justified.

Conclusions

The results indicated that:

- in the superhumid zone, the performance of the genotypes among the B, F and H2 soils was significantly different and justified the establishment of trials in each soil type.
• there was no significant interaction within H2 soils indicating consistent performance of the genotypes among the locations and replication of trials within H2 soils is not necessary.

• presence of a significant interaction within the B and the F soils implied the need to replicate trials in these soils in the different areas where these soils prevail.

• G×E interaction was very important in the subhumid zone and justified the establishment of more than one trial in each of the L and P soils.

• no significant G×E interaction between the L2 and H2 soils indicated that there is no need to replicate trials between these soils.

REFERENCES


USO DE DATOS HISTÓRICOS DE ENSAYOS DE VARIEDADES DE CAÑA DE AZÚCAR EN MULTIPLES LOCALIDADES PARA IDENTIFICAR LAS RELACIONES ENTRE AMBIENTES EN TERMINOS DE RESPUESTAS GENOTÍPICAS

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PALABRAS CLAVE: Análisis de AMMI, Producción de Caña (TCH), Genotipo× Interaccione Ambientales, Respuesta Genotípica, Ensayos de Localidades Múltiples, PCA.

Abstract
EN LA ISLA DE MAURICIO, la caña de azúcar se cultiva en varios ambientes que pueden ser agrupados en tres zonas: Súper-húmedo, Húmedo y Sub-húmedo. En cada zona, se establecen ensayos con varios genotipos cubriendo varias localidades para obtener información confiable e identificar variedades de alta producción. La interacción genotipo× ambiente (G× E) es el elemento más complicado para seleccionar genotipos aceptables para producción comercial. Sin embargo, uno de los aspectos difíciles para conducir experimentos en diferentes localidades, es escoger el sitio para el estudio, por ello es necesario planificar un programa racional de evaluaciones para obtener datos confiables. Datos históricos disponibles de cuatro series en ensayos de fase final establecidos en años diferentes fueron usados para el estudio de los efectos ambientales (E) y genotipo (G) así como las interacciones (G× E). El objetivo fue identificar las relaciones entre sitios en términos de la respuesta del genotipo y evaluar en qué magnitud los ambientes fue similar o diferente. Los resultados acumulativos de caña planta y tres socas para producción de caña (TCH) fueron analizados. En la zona súper-húmeda, localizada en mayor altitud, la interacción G× E no fue importante dentro de suelo rocoso (B) y los profundos y libres (F). En cambio una interacción significativa G× E se observó dentro de los suelos B y F en localidades ubicadas en altitudes medias y bajas de diferentes sectores. En forma similar, entre las localidades con suelos Humic Latosols (H2) y entre suelos H2 y L2, la interacción no fue prominente. Pero, los suelos del tipo B, F y H, podrían ser la causa de la diferente respuesta genética. En el suelo sub-húmedo, se observó alta significación de la interacción G× E entre todos los Latosoles Húmedos Bajos (L1, L2) y los Latosoles Rojizos de Pradera (P2 y P3). El estudio confirmó que los ensayos podrían establecerse principalmente en los suelos B, F, L y P, pero deberían ser replicados en los suelos B y F más comunes en los diferentes sectores de la isla.
SCREENING AGRONOMICALLY ACCEPTABLE CLONES FROM FAMILIES ASSESSED UNDER NON-MOISTURE LIMITING CONDITIONS IN A MANAGED MOISTURE-LIMITED ENVIRONMENT FOR ENHANCED PRODUCTIVITY AND DETERMINATION OF POSSIBLE SELECTION TRAITS

By

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Keywords: Moisture-Stress Tolerance, Managed Moisture Stress Screening, Cane Productivity, Post-Stress Rejuvenation.

Abstract

MOISTURE stress is the primary abiotic stress occurring in almost all cane growing areas of India, causing drastic reduction in cane and sugar productivity. Under this situation, development of productive, moisture-stress tolerant cultivars assumes greater importance to sustain cane and sugar production. Hence, the study was undertaken to identify families and traits of importance for genetic enhancement of sugarcane productivity under moisture-stress environment. A hybrid seedling population of 45 diverse inter-varietal crosses was studied for variability parameters and percent superior segregates for cane and sugar productivity in seedling and clonal generations under non-moisture stress and moisture-stress environments, respectively. Further, path analysis and mean performance were studied to identify important contributing traits for productivity under moisture stress involving 50 productive selections in clonal stage III with three standards. The polycrosses involving Co 8013, CoV 92101, C 81615, CoC 771, Co 8371, general crosses involving Co 88025 and CoC 671 as female parents, and a cross Co 740 × CoA 7602 exhibited a better range of variability for sugar and cane productivity and produced better percent superior/transgressive segregants. The genotypic path analysis involving six biophysical traits revealed that the light use efficiency (LUE) under moisture stress and photosynthesis rate after alleviation of stress through enhanced transpiration largely contribute to cane productivity. Similarly, the path analysis of 20 other traits under moisture stress emphasised the major role of early internode formation, root length and biomass, leaf area and leaf sheath moisture at the end of the formative stage for higher cane yield. The other traits like tiller number at the mid-formative stage and single cane weight (SCW i.e stalk weight) at harvest can also be considered as selection criteria for improvement of cane productivity. Hence, for genetic enhancement of sugarcane productivity under moisture-limited environments, the families/crosses identified could be considered as ‘proven’ for isolating productive moisture-stress tolerant progenies. The traits identified are effective and useful for identification of productive moisture-stress tolerant clones. Clones identified could be promoted to advanced yield trials.

Introduction

Moisture stress is one of the major constraints to improving sugarcane productivity in India. The extreme decline in the cane area and production due to drought is a strong reminder of the dependence of the sugarcane production on rainfall. The majority of the sugarcane area in the country experiences drought during the formative phase (60–150 DAP) which is the most sensitive growth stage (Naidu, 1976; Gascho and Shih 1983; and Venkataramana, 2003). In this context, for
sustained cane and sugar production, development of productive sugarcane cultivars which can tolerate moisture stress assumes greater importance.

In breeding for stress tolerance, cane yield and tolerance to the stress factors are to be considered, as the cane yield under stress is a function of genotype response to stress and the yield potential (Moore, 1987). Selection for stress tolerance in a suboptimal environment (moisture stress) may advance seedlings with poor yield potential. Hence, with this basic philosophy in view, initial seedling selection based on productivity features is conducted under non–moisture limiting conditions. Further, the fairly large selected population consisting of productive progenies is advanced to clonal stage-I and evaluated under moisture-limiting conditions to identify tolerant genotypes, families, and contributing traits.

The estimates of genetic variability parameters for cane and sugar yield component traits in seedling generation under non-moisture stress and in clonal stage I and its ratoon under moisture stress is reported in our earlier paper (Patil et al., 2008). The study identified the traits viz., tiller number, number of millable cane (NMC), single cane weight (SCW), and hand refractometer (HR) Brix (°) as most reliable and repeatable across seedling and clonal generations under non-moisture stress and moisture-stress environments, respectively.

In the present paper, the results obtained are discussed to identify families and traits contributing towards improved productivity under a moisture-stress regime. Further, the performance of top 10 productive clones is also discussed in the context of contributing traits.

Material and methods

The potted seedling population, comprising 3124 sturdy hybrid progenies derived from 45 diverse inter-varietal crosses, was transplanted to an augmented randomised block design –II, with 22 blocks and four commercial check cultivars viz., CoC 671, Co 86032, CoM 88121 and Co 740 at the Agricultural Research Station, Sankeshwar (University of Agricultural Sciences, Dharwad, Karnataka, India, 15°29’N, 74°59’E) under non-moisture stress conditions. The trial had an inter-row spacing of 0.9 m and an intra-row spacing of 0.6 m. Any gaps from failed seedlings were filled with corresponding hybrid seedlings after 15 days. Recommended cultural operations were carried out during the crop season with regular irrigation schedule based on 75% moisture depletion. The seedling population was evaluated for various cane yield traits viz., tillers per seedling (at 90 days after transplanting), cane girth (cm), millable cane height (cm), number of internodes, internode length, number of millable canes (NMC), single cane weight (SCW), cane yield per clump and HR Brix (°) (270 days after transplanting).

A total of 828 seedlings were selected based on superior or on par cane yield and/or HR Brix (°) compared to the best commercial check. The selected clones were planted in 3-m row length in an augmented RBD-II with nine blocks (CT-I) in a moisture-stress environment. Each block comprised 92 clones and four check cultivars planted randomly. The seed rate of 12 eye buds/m was followed with recommended practices under moisture stress. The stress was created by withholding irrigation from 50 to 160 days after planting (DAP), i.e., formative phase which generally coincides with summer months during which the crop generally suffers from moisture stress and the clones were scored for important cane yield traits and HR Brix (°) (330 DAP).

Fifty moisture-stress tolerant selections from clonal stage I and three commercial check cultivars were evaluated in RBD with two replications. The trial was planted in paired rows of 6 m length with spacing of 1.8 m and 0.9 m between and within pairs respectively. The seed rate (10 eye buds/m) and all standard management practices, excluding drought management practices, were followed for raising the crop. In this experiment, irrigations were skipped from 50–160 DAP and observations on various traits viz., physiological, biophysical, root parameters, cane and sugar components were recorded. The physiological traits viz., leaf area index (LAI) and mean tilt angle (MTA) of leaves at 150 DAP were measured by using portable LICOR canopy analyser system. The characters like 8th leaf area (as per Romero, 1987), leaf sheath and lamina moisture percent and
relative water content were also measured using standard procedures followed in sugarcane and other field crops. The portable photosynthesis system (LI-6400 LICOR, Nebraska, Lincoln., USA) was used to measure biophysical traits like rate of photosynthesis (µ mol CO₂/m²/s), transpiration (m mol of H₂O/m²/s), conductance (µ mol CO₂/m²/s), leaf temperature (°C), water use efficiency (µ mol CO₂/m mol of H₂O) and light use efficiency (µ mol CO₂/µ mol PAR). These observations were made on the top fully opened leaf, from 10 am to 12 noon, on both sampling stages i.e., at moisture stress (mid-formative phase) and after alleviation of stress (i.e., after irrigation at the end of formative phase). The root parameters like number and dry weight (g) per clump and root length were also recorded in cm.

The data collected on various traits were subjected to correlation and path analyses. The data were subjected to Anova and Anacova by the methods proposed by Cochran and Cox (1957). The genotypic correlation coefficients (r_G) among all the traits were determined from the variance and covariance components. The correlation coefficients were further partitioned into direct and indirect effects with the help of path coefficient analysis. The 10 most productive clones, relative to the commercial checks, were considered in detail to determine what traits may be important in determining productivity under moisture-limited conditions.

Results and discussion

Among 20 biparental crosses involving commercial cultivars, the cross Co 740 × CoA 7602 produced progenies with a better range for cane yield and HR Brix (°) with better percent superior progenies in normal irrigated environment (Table 1). Though one transgressive segregant was recovered from the cross in clonal stage III, the cross scored a lower percentage of superior progenies in the moisture-stress regime in clonal stage I.

Out of 17 poly crosses, five involving female parents Co 8013, Co 8371, CoC 771, CoV 92101, and C 81615 produced better percentage of superior progenies with a wide range of variability for cane yield and HR Brix (°) both in seedling and clonal generation under non-stress and stress environments. Transgressive segregates (productive) under moisture stress were recovered from all these five polycrosses. The CoV 92101 PC produced a maximum of three productive segregants.

Eight general crosses produced a better number of progenies wherein only two viz., Co 88025 GC and CoC 671 GC exhibited a better range of variability for both cane yield and HR Brix (%). Both the general crosses produced transgressive segregates under moisture stress.

Table 1—Contribution of families towards production of superior progenies/transgressive segregates.

<table>
<thead>
<tr>
<th>Family/cross</th>
<th>Seedling generation under normal irrigated</th>
<th>Clonal generation under moisture stress</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cane yield (kg/clump)</td>
<td>HR Brix (°)</td>
</tr>
<tr>
<td>Co 740 × CoA 7602</td>
<td>0.32–13.83</td>
<td>7.8–22.2</td>
</tr>
<tr>
<td>Co 8013 PC</td>
<td>0.59–10.80</td>
<td>12.4–21.0</td>
</tr>
<tr>
<td>Co 8371 PC</td>
<td>0.59–9.92</td>
<td>10.4–20.0</td>
</tr>
<tr>
<td>CoC 771 PC</td>
<td>0.61–10.27</td>
<td>9.0–19.1</td>
</tr>
<tr>
<td>CoV 92101 PC</td>
<td>0.60–10.64</td>
<td>10.0–19.0</td>
</tr>
<tr>
<td>C 81615 PC</td>
<td>0.80–11.25</td>
<td>10.0–19.0</td>
</tr>
<tr>
<td>Co 88025 GC</td>
<td>0.90–3.90</td>
<td>13.0–19.1</td>
</tr>
<tr>
<td>CoC 671 GC</td>
<td>0.76–8.46</td>
<td>5.9–19.4</td>
</tr>
</tbody>
</table>
Character association analysis in selected sugarcane progenies evaluated under moisture stress environment

In sugarcane, cane yield is a complex character influenced by a number of inter-related component traits. This often influences the direct relationship with cane yield and, as a result, the information based on correlation coefficients is not dependable. Since path coefficient analysis gives a more realistic relationship of characters, an attempt has been made in the present study to identify the effective components of cane yield having either positive or negative significant association with cane yield.

Path coefficient analysis was used in working out the direct (diagonal values) and indirect (off diagonal values) effects of 20 characters on cane yield per plot under moisture stress (data not presented). The genotypic path coefficient analysis accounted for a major part of the total variation in cane yield as indicated by relatively lower residual effects.

The results of the present investigation indicated some interesting facts. The characters like average number of internodes, tillers at 80 DAP, average root length and root number had a relatively high positive correlation with cane yield, but had negative direct effects. A similar observation was made by Patel et al. (1993). However, Khan et al. (2001) reported a positive association of number of internodes, number of millable canes and millable cane height with cane yield and positive direct effect.

From a breeder’s viewpoint, characters could be useful as selection criteria if they not only have a high positive correlation, but also exert high direct effects. In this context, number of internode formed shoots (at 120 DAP), single cane weight, average long root length, 8th leaf area, and leaf sheath moisture had a significant and positive association (correlation) with cane yield per plot and exerted high direct effect. Similar results were obtained by Bodhinayake et al. (1998), Kamat and Singh (2002) and Wagih et al. (2003). However, Srivastava et al. (1997) expressed a contrasting view to these findings.

Single cane weight, which is an important cane yield component, was highly significantly correlated with cane yield and with a better direct effect indicating its importance in enhancing cane yield. However, Bissessur et al. (2001) expressed that, in any environment, selection of a combination of traits is more important than any single trait.

The characters like cane height, number of internode formed shoots at 160 DAP, and root dry matter had a relatively high positive association with cane yield, but their direct effects were relatively lower indicating direct selection for these traits may not be effective under a moisture-stress environment. Bodhinayake et al. (1998) expressed similar views with respect to number of roots in the surface horizon.

The juice extraction percent, relative water content, and mean tilt angle (leaf angle) of leaves had a low non-significant negative association with cane yield but had higher direct negative effects suggesting higher cane yield genotypes can be identified with acute leaf angle.

Hence, from the genotypic path analysis study, for improvement of cane yield under moisture-limiting conditions, emphasis must be placed on the number of internode formed shoots at 120 DAP, single cane weight (at harvest), average long root length, 8th leaf area, and the leaf sheath moisture at the end of the formative stage.

The other traits like number of internode formed shoots at 160 DAP, cane height and girth at harvest also can be considered as additional selection criteria for improvement of cane yield, under moisture-limiting conditions.

Path coefficient analysis of bio physical traits for cane yield

Path coefficient analysis was used to determine the direct (diagonal values) and indirect (off diagonal values) effects of six biophysical traits under moisture stress and non stress (after alleviation) conditions on cane yield per plot (data not presented). The genotypic path coefficient
analysis accounted for only about 50 percent of the total variation in cane yield as indicated by considerable residual effects.

All the bio-physical traits under stress condition in the mid-formative stage had no significant association with cane yield. Similarly, little variation for photosynthetic traits among sugarcane clones was observed by Singh et al. (1994). Even after alleviation from stress, all the photosynthesis related traits except photosynthesis rate had non-significant association with cane yield, whereas photosynthesis rate only had significant positive association with cane yield indicating the clones differed significantly with respect to this parameter after alleviation from moisture stress. The cultivars also differed for their ability to recover from stress after irrigation. Ali et al. (2003) reported that drought tolerant clones had a remarkable ability to recover after re-watering if the stress period was not prolonged or too severe.

Photosynthetic rate after alleviation from stress (0.716) had the highest direct positive effect on cane yield, followed by Light Use Efficiency (LUE) under moisture stress (5.322). The highest negative direct effect on cane yield was from transpiration rate after alleviation of stress (–0.644) followed by photosynthetic rate under moisture stress (–6.001) (Table 2). This suggests that the varietal adjustment/adaptive ability under moisture stress through better light use efficiency and regaining higher photosynthesis rate after relief from stress are important parameters which had positive direct effects on cane yield, and high rate of photosynthesis after stress alleviation is equally important for rejuvenation of cultivars which was achieved through high transpiration. The better LUE under stress and high photosynthesis rate after alleviation of stress are important for mitigating stress and regaining normal (or enhanced) growth. Genotypes with such important features could be ideal under moisture stress, as results clearly indicated the role of these traits towards higher productivity. This finding is in accordance Adarsha (2004), who reported cotton genotypes responded for rejuvenation ability through higher stomatal conductance. Both the maintenance of photosynthetic ability in stress and better rejuvenation capacity after stress alleviation are important for imparting moisture stress tolerance in sugarcane progenies studied. Srivastava et al. (1996) reported the role of rejuvenation capacity for drought-tolerant cultivars Co 1148, Co 5769, and Co 5823 through high stomatal conductance and transpiration. The higher positive indirect contribution of photosynthesis rate to cane yield per plot was through LUE under stress.

Hence, from the genotypic path analysis study, LUE under stress and high photosynthesis rate after stress alleviation through high transpiration largely contribute to cane yield. Hence, for improvement of cane yield under moisture stress environments, emphasis must be placed on LUE under stress and high photosynthesis rate after stress alleviation as evidenced in productive progenies in the moisture-stress environment.

Contribution of important traits towards productivity under moisture stress

The analysis of variance of the replicated clonal data revealed highly significant differences among the genotypes for all characters except leaf temperature, WUE percent under stress, and 8th leaf area. The mean values for important contributory traits in the top ten superior cane yielding progenies over best check are given in Table 2.

The important cane yield components, single cane weight, NMC, and millable cane height played a major role among various other components, contributing towards excellence of nine progenies:- SNK 632, SNK819, SNK 822, SNK 827, SNK 024, SNK 813, SNK 707, SNK 782, and SNK 806 over the best check Co 86032.

The internodes formed shoots, root dry weight, average long root length, LAI, and 8th leaf area had a significant role among various physiological parameters studied in cane yield formation. The superior top 10 cane yielding progenies recorded a higher number of internode formed shoots even under moisture-stress condition indicating their tolerance to moisture stress or the potential to maintain growth rate under moisture-stress condition. The tolerance capacity could be due to higher...
root dry matter and deeper (long) root growth, features observed in top productive progenies compared to the best check Co 86032. In addition, these progenies also had higher leaf sheath moisture percent, lower leaf lamina moisture percent, and higher LAI and 8th leaf area.

The maintenance of a productive shoot population under moisture stress is an important character for better productivity. This was studied through mortality percent of tillers at 90 and 120 DAP, i.e., mid-formative stage under moisture stress. The top productive progenies exhibited lower mortality percent at the initial (90 DAP) stress period, whereas higher mortality was observed at later (severe) stages of moisture stress, thereby reducing total shoots per unit area. The progenies produced a higher number of productive shoots (internode formed shoots) compared to the check variety Co 86032. In the case of the moisture-stress sensitive variety Co 86032, though total shoot population maintained was high with reduced mortality, the productive shoots (internode formed shoots) were lower, thereby reducing single cane weight and lower NMC at harvest.

The top productive progenies did not differ much from the best check Co 86032 for all the photosynthesis related traits under the moisture-stress condition, indicating minimum role of these traits for imparting moisture stress tolerance. Instead, the high productive progenies SNK 632, SNK 819 and SNK 024 had inferior water use efficiency because of higher transpiration compared to checks. The higher productivity in spite of lower water use efficiency could be due to their inherent capacity to utilise moisture available at lower soil layers through a deep root system compared to the check cultivars which were more sensitive to moisture stress. Thereby these progenies maintain growth under stress at comparatively high expense of water, i.e., low water use efficiency.

The rejuvenation capacity after alleviation from moisture stress is also an important parameter for higher cane productivity under a moisture-stress environment. In the case of top productive progenies, SNK 632 and SNK 819, photosynthesis rate was significantly higher compared to the best check (Co 86032) after relief from stress (Table 2), indicating their higher rejuvenating potential to utilise available moisture, and this could also be due to a better root system.

The pedigree of these top productive progenies indicate that the crosses Co 8013 PC, CoV 92101 PC, C 81515 PC, Co 88025 GC, Co 740 × Co A7602, CoC 771 PC, Co 8371 PC, CoC 671 GC, and CoC 771 PC were promising for obtaining superior progenies to improve productivity under a moisture-stress environment. This indicates the role of parents, Co 740, CoA 7602, and Co 8013 in attributing drought tolerance to their progenies. These findings suggest the importance of family selection and also the role of parental selection with required features to obtain heterotic progenies combining better moisture-stress tolerance and higher productivity.

**Conclusion**

The bi-parental cross Co 740 × CoA 7602, the poly crosses involving female parents Co 8013, Co 8371, CoC 771, CoV 92101 and C 81615 and general crosses involving female parents Co 88025 and CoC 671 found proven on the basis of variability obtained for cane yield and HR Brix (°) and recovery of transgressive segregates. For improvement of cane productivity under a moisture-stress regime, emphasis must be placed on traits like early cane internode formation, stalk weight at harvest, root length and leaf sheath moisture at end of formative phase. Among biophysical traits, the light use efficiency at stress and photosynthesis rate after alleviation of stress are important for identification of productive genotypes. The performance of the top 10 productive hybrid progenies clearly demonstrated the contribution of the above traits towards improved productivity under moisture stress. The productive progenies could be promoted to advanced yield trials and also be utilised in current breeding programs as donors for moisture-stress tolerance.

**REFERENCES**

Table 2—Mean values of important contributing traits for top 10 superior cane yielding progenies over best check under moisture stress environment.

| Clone       | Cross          | Tillers/pl at 90 DAP | No. Int. formed shoots/plot at 120 DAP | No. Int. formed shoots/plot at 160 DAP | Root dry. wt (g)/clump at 150 DAP | Av. root length (cm) at 150 DAP | Area 8th leaf area at 150 DAP (cm²) | Leaf sheath moisture % at 150 DAP | At stress LUE % (Physio.) | Photo-synthesis rate following stress alleviation | Trans-Piration rate following stress alleviation | Average SCW (kg) at harvest | NMC (000’s/ha) | CCS% | CCS% at harvest | Cane yield (t/ha) |
|-------------|----------------|----------------------|----------------------------------------|----------------------------------------|----------------------------------|---------------------------------|----------------------------------|----------------------------------|---------------------------------|-----------------------------------------------|-----------------------------------------------|----------------------------|-------------|-----------------|------------------|
| 1. SNK 632  | Co 8013 PC     | 138                  | 48                                     | 68                                     | 3.18                             | 21.53                           | 276                              | 46.7                             | 3.96                            | 58.46                          | 4.42                           | 2.05                      | 53.4        | 12.46           | 11.4             | 109.6             |
| 2. SNK 819  | CoV 92101 PC   | 266                  | 33                                     | 58                                     | 2.10                             | 17.77                           | 380                              | 34.0                             | 3.38                            | 62.00                          | 3.64                           | 2.01                      | 48.7        | 10.56           | 10.8             | 98.1              |
| 3. SNK 822  | C 81615 PC     | 187                  | 34                                     | 82                                     | 2.57                             | 23.10                           | 302                              | 44.9                             | 3.69                            | 59.42                          | 3.51                           | 1.62                      | 58.1        | 10.94           | 11.6             | 94.4              |
| 4. SNK 827  | Co 88025 GC    | 247                  | 28                                     | 81                                     | 2.44                             | 24.20                           | 292                              | 44.1                             | 3.43                            | 54.32                          | 4.11                           | 2.05                      | 45.4        | 10.46           | 11.2             | 93.4              |
| 5. SNK 24   | Co 740 x CoA 7602 | 184                  | 53                                     | 71                                     | 2.34                             | 17.85                           | 291                              | 29.9                             | 3.42                            | 54.08                          | 3.47                           | 1.53                      | 61.3        | 10.24           | 11.3             | 90.7              |
| 6. SNK 813  | CoC 771 PC     | 267                  | 9                                      | 78                                     | 2.40                             | 27.10                           | 279                              | 44.2                             | 3.50                            | 58.51                          | 4.21                           | 1.52                      | 58.2        | 10.76           | 12.1             | 88.8              |
| 7. SNK 707  | Co 8371 PC     | 242                  | 5                                      | 66                                     | 1.69                             | 22.84                           | 290                              | 46.2                             | 3.63                            | 59.81                          | 4.31                           | 1.25                      | 69.9        | 11.52           | 13.3             | 86.9              |
| 8. SNK 782  | CoC 671 GC     | 195                  | 15                                     | 77                                     | 1.62                             | 19.51                           | 292                              | 39.4                             | 3.54                            | 60.28                          | 4.26                           | 1.30                      | 66.8        | 10.69           | 12.3             | 86.9              |
| 9. SNK 806  | CoC 771 PC     | 255                  | 19                                     | 50                                     | 1.90                             | 20.10                           | 293                              | 43.8                             | 3.62                            | 58.91                          | 4.24                           | 1.63                      | 52.7        | 10.73           | 12.5             | 86.0              |
| 10. SNK 809 | CoC 771 PC     | 205                  | 21                                     | 62                                     | 2.88                             | 26.25                           | 269                              | 36.9                             | 3.69                            | 57.71                          | 3.82                           | 1.48                      | 58.2        | 9.67            | 11.6             | 83.7              |
| Checks      |                |                      |                                        |                                        |                                  |                                 |                                   |                                  |                                 |                                |                                |                           |             |                 |                  |
| CoC 671     |                | 170                  | 26                                     | 52                                     | 1.20                             | 20.15                           | 327                              | 40.8                             | 4.23                            | 59.64                          | 3.47                           | 1.62                      | 39.6        | 8.82            | 13.7             | 64.3              |
| Co 86032    |                | 201                  | 17                                     | 66                                     | 1.38                             | 19.50                           | 242                              | 40.8                             | 3.32                            | 52.83                          | 3.50                           | 1.57                      | 42.6        | 8.79            | 13.1             | 67.0              |
| CoM 88121   |                | 222                  | 4                                      | 71                                     | 0.78                             | 17.28                           | 208                              | 46.5                             | 3.78                            | 52.54                          | 2.75                           | 1.37                      | 43.6        | 7.97            | 13.4             | 59.7              |
| CD(0.05)    |                | 51.6                 | 10.8                                    | 13.9                                   | 1.00                             | 4.85                             | 60.8                             | 0.7                              | 0.68                            | 5.13                           | 0.40                           | 0.37                      | 19.3        | 0.08            | 1.1              | 6.8               |
| MEAN        |                | 184.4                | 13.7                                    | 59.1                                   | 1.89                             | 18.01                           | 247.5                            | 39.4                             | 3.67                            | 55.12                          | 3.62                           | 1.41                      | 45.2        | 7.24            | 11.6             | 62.6              |
| RANGE       |                | 88.5–266.5           | 0.0–53.3                                | 26.5–90.9                              | 0.45–4.44                        | 10.24–27.10                      | 173.4–379.9                      | 25.3–48.1                        | 3.12–4.71                       | 41.83–62.88                    | 2.42–5.09                       | 0.872–2.05                  | 17.3–74.6   | 6.50–12.46      | 6.5–13.4         | 21.9–109.6        |


SÉLECTION DES CLONES ISSUS DES FAMILLES ÉVALUÉES SANS STRESS HYDRIQUE DANS UN ENVIRONNEMENT CONTRÔLÉ LIMITÉ EN EAU ET IDENTIFICATION DES CARACTÈRES DE SÉLECTION APPROPRIÉS

Par

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Résumé

Le stress hydrique est le principal facteur abiotique prévalent dans presque toutes les régions cannières de l’Inde, occasionnant une baisse sévère de la productivité en sucre. Sous ces conditions, le développement des cultivars productifs, tolérants au stress hydrique revêt une grande importance pour maintenir la production sucrière. Par conséquent, cette étude a été entreprise afin d’identifier les familles et les caractères appropriés pour sélectionner des génotypes améliorés capables de rehausser la productivité sous un régime de stress hydrique. Une population de plantules issues de 45 combinaisons génétiques ont été étudiées sur les générations clonales issues de plantules et de boutures pour leur paramètres de variabilité génétique à l’aptitude à produire des clones supérieurs pour le rendement en canne et en sucre en absence et en présence de stress hydrique respectivement. De plus, l’analyse des pistes et la performance moyenne ont été étudiées pour identifier les caractères importants contribuant au rendement sous les conditions de stress hydriques chez 50 génotypes sélectionnées au stade clonal III avec trois témoins. Les polycroisements impliquant Co 8013, CoV 92101, C 81615, CoC 771, Co 8371, des croisements généraux comprenant Co 88025 et CoC 671 comme parent femelle et un croisement Co 740 × CoA 7602 ont démontré une large gamme de variabilité pour le rendement en canne et en sucre et produit un pourcentage plus élevé d’individus transgressifs et supérieurs. L’analyse des pistes génotypiques comprenant six caractères biophysiques ont démontré que l’efficience de l’utilisation de la lumière (LUE) sous conditions de stress hydrique et le taux de photosynthèse après allègement du stress par la transpiration accentuée ont contribué largemen t au rendement canne. De même, l’analyse des pistes de 20 autres caractères sous des conditions de stress hydrique a souligné le rôle majeur de la formation précoce des entrenœuds, la longueur des racines et la biomasse, la surface foliaire et l’humidité de la gaine en fin de stade de développement pour des rendements plus élevés. Les autres caractères comme le tallage à mi-chemin du stade de formation, et le poids de la tige (SCW) à la récolte peuvent aussi être considérés comme critères de sélection pour améliorer le rendement. Par conséquent, pour le rehaussement génétique de la productivité de la canne dans les environnements de stress hydrique, les familles/croisements identifiés pourraient être considérés comme « éprouvés » pour l’identification de descendance tolérante et plus productive sous les conditions de stress hydrique. Les caractères identifiés sont efficaces et utiles pour la sélection des clones performants et tolérants au stress hydrique. Ces clones pourraient être promus au stade essais variétaux.
PRUEBAS DE CLONES AGRONÓMICAMENTE ACEPTABLES DE FAMILIAS EVALUADAS BAJO CONDICIONES LIMITADAS DE POCA HUMEDAD USANDO UN AMBIENTE CONTROLADO CON LIMITACIONES DE HUMEDAD PARA INCREMENTAR LA PRODUCTIVIDAD Y DETERMINACIÓN DE POSIBLES CARACTERES DE SELECCIÓN

Por

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PALABRAS CLAVE: Tolerancias a Estrés por Humedad, Evaluaciones de Estrés Bajo Condiciones Controladas, Producción de Caña, Rejuvenecimiento Pos-Estrés.

Resumen

EL ESTRÉS por humedad es el principal estrés que ocurre en casi todas las aéreas cañeras de la India, causando reducciones drásticas en la producción de caña y azúcar. Bajo estas circunstancias, el desarrollo de cultivares productivos y tolerantes al estrés por humedad es de gran importancia, para sostener la producción de caña y azúcar. Por ello, el estudio se llevó a cabo para identificar familias y caracteres de importancia para mejorar genéticamente la productividad bajo condiciones ambientales de estrés. Una población híbrida de 45 cruzas intervarietales fue estudiada para identificar la variabilidad de parámetros y el porcentaje de segregantes superiores para producción de caña y azúcar en plántulas de semilla sexual y trozos de generaciones clonales bajo condiciones ambientales de no-estrés y estrés, respectivamente. También, se realizó el análisis de sendero y el comportamiento promedio para identificar los caracteres importantes que contribuyen a la productividad bajo condiciones ambientales de estrés de 50 materiales seleccionados de Estado III con tres testigos. Los policruzamientos que incluyen Co 8013, CoV 92101, C 81615, CoC 771, Co 8371, y las cruzas generales con Co 88025 and CoC 671 como padres femeninos, y una cruz de Co 740 × CoA 7602 mostraron un mejor rango de variabilidad en producción de azúcar y caña, así como un mejor porcentaje de segregantes trangresivos superiores. El análisis de sendero del genotipo que incluyó seis caracteres biofísicos mostró que la eficiencia del uso de la luz (LUE) bajo estrés de humedad y la tasa de fotosíntesis luego de disminuir el estrés a través de la transpiración, contribuyó enormemente para la producción de caña. En forma similar el análisis de sendero para otros 20 caracteres bajo estrés de humedad mostró un rol principal en la formación temprana de los entrenudos, largo de raíz y biomasa, área de hoja y humedad de de la superficie de la hoja al final del estado formativo para alta producción de caña. Los otros caracteres como número de tallos en la mitad del estado formativo y el peso de tallos individuales (SCW) a la cosecha pudieron usarse como criterios de selección para mejorar la producción de caña. Para el mejoramiento de la producción de caña bajo condiciones limitadas de humedad, las familias/cruzas identificadas pudrían ser consideradas como ‘pruebas’ para separar progenies tolerantes y productivas bajo condiciones de estrés por humedad. Los caracteres identificados son útiles y efectivos para la identificación de clones tolerantes y promover su uso para otros ensayos de rendimiento.
EFFECT OF ALTITUDE ON SUGARCANE FLOWERING SYNCHRONISATION IN CUBA

By

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KEYWORDS: Sugarcane, Flowering, Synchronisation.

Abstract

SUGARCANE breeders have found some difficulties in making crosses associated with flowering induction and synchronisation. The objectives of this investigation were to evaluate the relative importance of the factors involved in the altitude for sugarcane flowering induction and to establish the basis of a controlled breeding program. This study is related to flowering of 100 sugarcane cultivars from 1990–2007 at three altitudes (100, 400 and 800 m above sea level) in Cuba. Sugarcane flowering is primarily in response to photoperiod, and it is conditioned by additional factors that can reduce, inhibit or delay it. In September, the average maximum (28–30°C) and minimum (21–22°C) temperatures were optimum for flowering. The extent of flowering was much greater at 400 m, with a marked reduction at 100 m, and intermediate at 800 m. In Cuba, late-flowering sugarcane cultivars start to tassel in the first week of December. At lower altitude, the same cultivars have earlier flowering by an average of 2–4 weeks. A negative linear correlation between percentage of pollen fertility and altitude was observed. In the study, a rise in altitude was accompanied by a large drop in maximum temperature and very little change in the minimum range. Growing cultivars in nurseries at different altitudes proved a useful tool to increase the clonal range and extent of flowering in Cuba.

Introduction

Sugarcane flowering is a complex physiological process consisting of multiple stages of development, each stage having specific environmental and physiological requirements (Julien, 1972).

Natural flowering is variable because it is affected by environmental factors such as daylength, temperature, moisture and nutrition.

Flowering of parental clones is restricted to specific periods, but there are clones that flower at different dates and therefore cannot be used easily in crossing (Nuss and Berding, 1999).

The Cuban sugarcane breeding program began at Cienfuegos in 1905 and it continues until the present time. At this time, Cuban National Center for Sugarcane Hybridisation is located in Sancti Spíritus (Caraballosol et al., 1999/2000).

Sugarcane flowers naturally in Sancti Spíritus, but the number of clones, intensity and flowering date, as well as the fertility of pollen, is different among sites located in different altitudes and years (Aguilar and Debernardi, 2004).

The objectives of this investigation were to evaluate the relative importance of the factors involved in the altitude for sugarcane flowering induction and to establish the basis of a controlled breeding program.
Materials and methods

Experimental locations

The trial was carried out at three locations in the Cuban National Center for Sugarcane Hybridisation (NCH), located in different altitudes within Guamuhaya’s mountains (Table 1).

<table>
<thead>
<tr>
<th>Table 1—Geographic position of the test locations.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>North Latitude</td>
</tr>
<tr>
<td>West longitude</td>
</tr>
<tr>
<td>Altitude (masl)</td>
</tr>
</tbody>
</table>

masl = metres above sea level

Photoperiod at Cuban National Center for Sugarcane Hybridisation

The three experimental sites have similar latitude (22°). The sunrise and sunset data used were obtained through the Spanish Armada’s web site:
http://www.armada.mde.es/ArmadaPortal/page/Portal/ArmadaEspannola/ciencia_observatorio/03_Efemerides--01_Sol--02_Salidas_es

The duration of the day was calculated, and the inductive period was determined, considering that it is produced between times while the day lasts for 12.5 and 12.0 hours. With these data, the time of daily decrease was also calculated using the formula

\[
\text{Daily decrease} = \frac{30}{IP},
\]

where IP = Inductive period (days) and 30 are the minutes for daylength of the IP.

Climate of experimental locations

Data were provided by the Cuban National Meteorology’s Institute for the three altitudes over an 18 year period. Variables taken monthly were:

- Maximum average temperature (Tx)
- Minimum average temperature (Tn)
- Maximum average relative humidity (RHx)
- Minimum average relative humidity (RHN)
- Total rainfall (TR)
- Day with rainfall (DR)

Each variable was divided in three ranges (high, middle and low) as it is indicated in Table 2. This information was used to calculate the range of temperatures and its relationship with flower induction.

<table>
<thead>
<tr>
<th>Table 2—Values range for climate variables.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
</tr>
<tr>
<td>Tx (° Celsius)</td>
</tr>
<tr>
<td>Tn (° Celsius)</td>
</tr>
<tr>
<td>RHx (%)</td>
</tr>
<tr>
<td>RHN (%)</td>
</tr>
<tr>
<td>TR (mm)</td>
</tr>
<tr>
<td>DR (days)</td>
</tr>
</tbody>
</table>
Plant material

**Cultivars**

One hundred random cultivars from the Cuban Sugarcane Germplasm Bank, with a wide genetic variability, were used in the study. For each cultivar, number of stalks, flowered stalks and percentage of flowered stalks (PFS) were analysed. Date of flower emergence (DFE) and percentage of pollen fertility (PFP) also were recorded.

Results and discussion

**Flowering by test locations**

Buenos Aires, located at 400 m altitude, was the site with highest and earliest flowering, and intermediate values for pollen fertility (Figures 1–3). Mayari, located at 800 m altitude, was the site with latest flowering and had lower pollen fertility than Guayos, located at 100 m altitude. Those results enable the design of a strategy for sugarcane flowering synchronisation and sex management in cultivars flowering at the three test locations.

![Fig. 1—Flowering intensity by location.](image)

![Fig. 2—Date of first flower emergence by location.](image)

![Fig. 3—Pollen fertility by location.](image)

Comparisons among locations of different altitudes have been carried out in some countries. Van-Breemen et al. (1963) report greater flowering in Km 14 area, located at 450 m altitude in the Dominican Republic, while Clements and Awada (1964) found a tendency for greater flowering above 390 m in Hawaii. On the other hand Yeu (1980), in China, reported better flowering 335 m in the town of Chungshen. In Australia Pollock (1981) found good flowering in Walkamin at 580 m. Nayamuth et al. (2003) in Mauritius reported a tendency to better flowering with altitude. Aguilar and Debernardi (2004) studying the variety CP72-2086 at different altitudes of Mexico reported better flowering at 292 to 477 m. In Guatemala, Polo (2005) reported good flowering at two heights (300 and 760 m).

**Inductive period in NCH**

The inductive period in the NCH (22° north latitude) is from days 247 to 272. That is to say, from 4–29 September, totalling 26 days with a decrease of 1.15 minutes/day (Figure 4).

![Fig. 4—Photoperiod at 22° north latitude (1: flower induction; 2: daylength; 3: sunrise with morning twilight; and 4: sunset with morning and evening twilight).](image)
Value of decreasing of 1 minute per day has been used in some countries to produce flowers in artificial conditions (Brett and Harding, 1974; Miller and Li, 1995; Nuss and Berding, 1999; Silva et al., 2005; Berding et al., 2007). This analysis suggests that the photoperiod is not a problem for flowering under our study conditions.

**Flowering and climate relation**

The temperature (maximum and minimum) was the climate variable with the greatest influence on flowering (Table 3). The other variables didn't have such a marked influence. These would be associated with no difference between locations for rainfall. In contrast, the temperature, mainly maximum, decreases with altitude.

### Table 3—Analysis of variance of flowering intensity for climate variables.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean squares</th>
<th>F-value</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tx</td>
<td>2</td>
<td>25 716.15</td>
<td>12 858.07</td>
<td>157.97</td>
<td>0.00</td>
</tr>
<tr>
<td>Tn</td>
<td>2</td>
<td>3666.68</td>
<td>1833.34</td>
<td>22.52</td>
<td>0.00</td>
</tr>
<tr>
<td>RHx</td>
<td>2</td>
<td>102.29</td>
<td>51.14</td>
<td>0.63</td>
<td>0.54</td>
</tr>
<tr>
<td>RHn</td>
<td>2</td>
<td>214.43</td>
<td>107.22</td>
<td>1.32</td>
<td>0.28</td>
</tr>
<tr>
<td>TR</td>
<td>2</td>
<td>58.52</td>
<td>29.26</td>
<td>0.36</td>
<td>0.70</td>
</tr>
<tr>
<td>DR</td>
<td>2</td>
<td>18.80</td>
<td>9.40</td>
<td>0.12</td>
<td>0.89</td>
</tr>
<tr>
<td>Error</td>
<td>51</td>
<td>4150.9</td>
<td>81.39</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The mean values for temperature are the best indicators for flowering potential (Figures 5 and 6). The best results were obtained at the experimental site located at 400 m (Buenos Aires). Optimum values of temperature reported by Nuss (1980) ranged 23–28°C, while Berding (2005) considered critical temperature for flowering to be 21–32°C.

Table 4 shows a sudden decrease in the maximum temperature with altitude but not in the minimum temperature. As a result, there is a narrower range between the temperatures. Clements and Awada (1967) reported an appropriate flowering in ranges of temperatures between 6–10°C.

### Table 4—Mean values of maximum and minimum temperature (°C) and their difference by locations.

<table>
<thead>
<tr>
<th>Locality</th>
<th>Altitude (m)</th>
<th>Tx</th>
<th>Tn</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guayas</td>
<td>100</td>
<td>31.6</td>
<td>22.4</td>
<td>9.2</td>
</tr>
<tr>
<td>Buenos Aires</td>
<td>400</td>
<td>28.4</td>
<td>21.7</td>
<td>6.7</td>
</tr>
<tr>
<td>Mayari</td>
<td>800</td>
<td>27.1</td>
<td>19.8</td>
<td>7.3</td>
</tr>
</tbody>
</table>
Flowering is sensitive to decreases in low temperature (Coleman, 1962). Panicle emergence is delayed at temperatures below 21°C (Clements and Awada, 1967, Nuss and Brett, 1977). Lower temperature increases the time for emergence of the panicle, but also the final duration (Edwards and Paxton, 1979). When night temperatures rise, flowering could be increased by 11 days in the tropics (Berding, 1981).

The development of the pollen is especially sensitive to cold temperatures (Brett, 1950; Levi et al., 1978; Chilton et al., 1967; Berding, 1981). Dunckelman (1967) was able to increase or to induce pollen fertility of sugarcane parents through the control of the climate (introducing the plants at night inside a glasshouse) and selection of male progenitors. The pollen fertility decreases when temperature is lower than 18°C or higher than 27°C (Nuss and Berding, 1999; Moore, 1987). According to optimum flowering temperature values (Table 5), the best location to exploit flowering, in Cuba, was Buenos Aires.

Table 5—Sugarcane optimum flowering temperature for different world locations.

<table>
<thead>
<tr>
<th>Location</th>
<th>Country</th>
<th>Tx</th>
<th>Tn</th>
<th>Difference</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coimbatore</td>
<td>India</td>
<td>31.5</td>
<td>22</td>
<td>9.5</td>
<td>Rao et al. (1973)</td>
</tr>
<tr>
<td>Groves</td>
<td>Barbados</td>
<td>28.2</td>
<td>22.7</td>
<td>5.5</td>
<td>Rao et al. (1973)</td>
</tr>
<tr>
<td>Tapachula</td>
<td>Mexico</td>
<td>29.4</td>
<td>19.6</td>
<td>9.8</td>
<td>Rao et al. (1973)</td>
</tr>
<tr>
<td>Romana</td>
<td>Dominican Rep.</td>
<td>26.8</td>
<td>19.9</td>
<td>6.9</td>
<td>Rao et al. (1973)</td>
</tr>
<tr>
<td>Kailua</td>
<td>Hawaii</td>
<td>28.1</td>
<td>21.9</td>
<td>6.2</td>
<td>Coleman (1960)</td>
</tr>
<tr>
<td>Km. 14</td>
<td>Dominican Rep.</td>
<td>27.3</td>
<td>20.6</td>
<td>6.7</td>
<td>Ellis et al. (1967)</td>
</tr>
</tbody>
</table>

Conclusions

- Buenos Aires is the location for highest flowering in Cuba, of the locations studied. It is located at 400 m altitude, with the best ranges of maximum (28–30°C) and minimum (21–22°C) temperature, in the month of September when the inductive period takes place, with similar values at other sites of good flowering in the northern hemisphere.
- There were differences in cultivars flowering date and pollen fertility among the locations studied. They enable the design of a breeding program with greater use of the parents flowering in these three locations through their synchronisation.

REFERENCES


EFFET DE L’ALTITUDE SUR LA SYCHRONISATION DE LA FLORAISON À CUBA

Par

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MOTS-CLÉS: Canne à Sucre, Floraison, Synchronisation.

Résumé

Les généticiens-sélecteurs ont des difficultés pour réaliser des croisements en raison des problèmes liés à l’induction et à la synchronisation de la floraison. Les objectifs de ce travail visent à étudier l’importance relative de l’altitude sur la floraison et d’établir les bases pour l’hybridation contrôlée. L’étude concerne l’influence de l’altitude (100, 400, et 800 m au-dessus du niveau de la mer) sur la floraison de 100 cultivars de canne à sucre à Cuba entre 1990-2007. La floraison de la canne à sucre est fonction de la photopériode, mais elle est aussi tributaire d’autres facteurs qui peuvent réduire le taux de floraison, l’entraver ou la retarder. En septembre, les températures moyennes maximales (28–30°C) et minimales (21–22°C) conviennent à la floraison. Le taux de floraison était plus important à 140 m, intermédiaire à 800 m avec une réduction marquée à 100 m. À Cuba, les cultivars à floraison tardive fleurissent dans la première semaine de décembre. La floraison de ces cultivars est avancée de 2-4 semaines en moyenne à une élévation inférieure. Une corrélation négative linéaire a été observée entre la fertilité pollinique et l’altitude. Une élévation croissante engendre une baisse significative des températures maximales mais avait peu d’effet sur les minimales. La plantation des pépinières de cultivars à différentes altitudes augmente les possibilités de floraison pour le programme d’hybridation à Cuba.
EFECTO DE LA ALTITUD SOBRE LA sincronización DE LA floración DE LA CAÑA DE ÁZUCAR EN CUBA

Por

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PALABRAS CLAVES: Caña de Azúcar, Floración, Sincronización.

Resumen

Los mejoradores de caña han encontrado dificultades para realizar cruzas en relación al florecimiento y su sincronización en caña de azúcar. Los objetivos de este estudio fueron estudiar la importancia relativa de los factores que se involucran con la altitud para el florecimiento de la caña de azúcar y establecer las bases para un sistema controlado de cruzamientos. El estudio relaciona al florecimiento de 100 cultivares entre 1990–2007 en tres altitudes (100, 400 and 800 m sobre el nivel del mar) en Cuba. La floración de la caña de azúcar está dada principalmente por el fotoperíodo y está condicionada por varios factores que pueden reducir, inhibir o demorar el proceso. En Septiembre, el promedio de temperatura máxima (28–30°C) y mínimo (21–22°C) fueron óptimos para la floración. La floración se extendió mejor a los 400 m de altitud, con una reducción marcada a los 100 m, e intermedia a los 800 m. En Cuba, las variedades que florecen tardíamente inician con un promedio de 2–4 semanas más temprano. Un correlación lineal negativa entre el porcentaje de la fertilidad del polen y la altitud fue claramente observada. El estudio mostró que un incremento en la altitud estuvo acompañada por una baja de la temperatura máxima y un pequeño cambio dentro del rango mínimo. El estudio demostró que al sembrar cultivares en parcelas a diferentes altitudes es una herramienta útil para incrementar el rango de clones a usarse y extender la floración en Cuba.
DEVELOPMENT OF SUGARCANE VARIETIES IN COLOMBIA
FOR SITE-SPECIFIC AGRICULTURE

By
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KEYWORDS: Sugarcane, Varieties, Agroecological Zones, Site-Specific Agriculture.

Abstract
SUGARCANE variety CC 85-92 is currently planted on more than 69% of the area in sugarcane in Colombia, a situation that is of concern in light of possible disease problems that could affect the productivity of the industry. Thus, CENICAÑA has focused on selecting varieties within the framework of site-specific agriculture. After the regional trials, from three to five varieties per series that are equal to or better than the check used in these trials are made available to the sugar mills. The most promising varieties then undergo a process of multiplication and monitoring to determine response to different agroecological zones and to make available to the growers more varieties with site-specific adaptation. To date, varieties CC 92-2804, CC 93-3895 and CC 93-4418 stand out. In the semidry zone, these three varieties yielded equal to or better than CC 85-92, thereby constituting promise for the industry.

Introduction
The Colombian Sugarcane Research Center (CENICAÑA) considers the selection and development of a sugarcane variety as the result of integrating the knowledge of its researchers, agronomists from the sugar mills, and sugarcane growers who seek to increase the productivity and profitability of a given agroecological zone. The approach used in CENICAÑA’s field research is site-specific agriculture (SSA), which provides the framework for the Variety Program in its varietal selection and development processes. The fourth version of the agroecological zoning of the Cauca River Valley, based on a detailed study of soils and the regional water balance, established the existence of 149 agroecological zones in the 216 764 ha studied (Carbonell et al., 2009).

The progress made in selecting and developing varieties within the framework of SSA, the identification of the agroecological zones where certain varieties have greater productivity, and the definition of different alternatives for planting varieties in the different agroecological zones of the Colombian sugar sector are presented here.

Materials and methods
Agroecological zoning
The fourth approximation of the agroecological zones for the sugarcane crop in the Cauca River Valley was based on a detailed study of soils (scale 1:10 000) that the sector carried out in the total area planted with sugarcane (216 764 ha) as of 2002 and on more complete information on daily rainfall coming from 216 pluviometric stations for more than 15 years. The new agroecological zones were formed in accordance with the following factors: (a) regional water balance, which includes rainfall and evapotranspiration; (b) a detailed study of soils in the area planted with cane in the Cauca River Valley; (c) homogeneous soil groups, defined on the basis of soil texture, moisture regime and effective depth of the soil or the distance that the roots of plants can penetrate without chemical or physical barriers; and (d) water regime groups formed in accordance with the water balance and the permeability of the soil and adjusted for signs of poor drainage, depth and the slope of the terrain. The agroecological zoning was generated with the
Geographic Information System, while statistical methods and geostatistics were used to analyse the data. A total of 149 zones were identified (Carbonell et al., 2009).

**Selection sites**

To facilitate the selection of varieties within the SSA approach, the 149 agroecological zones were regrouped on the basis of two criteria: water regime and soil texture, forming three zones: Semidry, Wet and Piedmont. Selection sites were established in each zone, where parallel processes of plant breeding are being carried out, facilitating the selection and development of varieties for the different agroecological zones of the sugar sector.

Selection for the Semidry Zone is centralised at CENICAÑA’s San Antonio de los Caballeros Experiment Station (SAES). Selection for the Wet Zone is carried out at the Cachimbalito Sugar Estate (Incauca S.A.) and occasionally at the La Cabaña or La Victoria sugar estates (La Cabaña Sugar Mill). Selection for the Piedmont Zone is done primarily on the Piedechinche Sugar Estate (Providencia Sugar Mill) and occasionally on Los Ranchos Sugar Estate (Central Castilla Sugar Mill).

**Germplasm evaluation**

At each of the varietal selection sites, CENICAÑA’s germplasm bank (1305 entries) was evaluated, identifying the varieties that were adapted best to each zone and then forming elite parental groups. The selection of the parents to be used in the crosses was done using the System of Information of Varieties – SIVAR, where there is a specific module for programming crosses. This module uses an algorithm that takes into account varietal traits such as sucrose (% cane), stalk diameter, leaf shedding, flowering, tillering, lodging, population and height, which are scored by means of descriptors that are expressed in relation to the check, as well as resistance to smut, rust and mosaic diseases, which are scored in accordance with the international scales proposed by the International Society of Sugar Cane Technologists (ISSCT) (Viveros et al., 2009).

**Selection of clones**

For each of the varietal improvement sites, specific crosses are designed and made each year, both at the SAES and at the Sugarcane Research Station in Tapachula, Mexico, due to high naturally flowering induction. True seed is planted in each varietal improvement site to establish seedling populations where selection is carried out at the different stages. In Stage I, the selection is done by family, identifying the best crosses for sucrose in the plant crop, and then in the first ratoon selecting the best individuals phenotypically that pass on to Stage II. Then, the best clones are selected for continuing on to Stage III and are planted in two agroecological zones for two crops, at the end of which varieties are selected for the regional trials, which are planted in the principal agroecological zones of the Cauca River Valley. The regional trials are established at the sugar mills with the largest area in the agroecological zones of greatest interest in order to obtain the best coverage possible. The regional trials are set up in experiments with a lattice design: 6-furrow strips along the plot with 3 replications over 3 crops. This experimental design gives varietal production results very similar to their performance on a commercial scale (CENICAÑA, 2008).

**Monitoring and multiplication**

At the end of the process, approximately 9–9.5 years after several cycles of selection, certain varieties stand out for their productivity in terms of TCH, sucrose (% cane) and TSH. Although the information that is available about these varieties comes from small areas, the results characterise the best varieties with respect to the check and orient the multiplication for conducting the final evaluations on harvest, lifting, transportation and delivery of the cane, as well as factory processes. CENICAÑA, together with the sugar mills and growers, carries out the planting and multiplication of the new varieties, identifying the sites or agroecological zones where those new varieties have a level of productivity higher than the most cultivated variety in the zone. Similarly, agroecological zones are identified where those varieties are equal to or have slightly less productivity than the
most cultivated variety in the same zone. In this way, the sites, agroecological zones or niches are identified where the new varieties warrant planting or where they should be because of low productivity.

Results and discussion

Selection sites

The 149 agroecological zones identified by Carbonell et al. (2009) were regrouped according to the water regime groups and the textural classes of the soil, thereby forming (a) the **Semidry Zones** (H0, H1 and H2 as described by Carbonell et al. (2009)), comprising 41 of the 149 agroecological zones, except for those located in the Piedmont of the Eastern and Western Andean mountain ranges, for a total of 135,975 ha; (b) the **Wet Zones** (H3, H4 and H5), which comprise 47 of the 149 agroecological zones, excluding those located in the Piedmont of the Eastern and Western Andean mountain ranges, for a total of 55,345 ha; and (c) the **Piedmont Zones**, which comprise 61 of the 149 agroecological zones in accordance with the groups of soils located in the Piedmont of the Eastern and Western Andean mountain ranges, but without taking into account the water regime conditions. This zone is comprised of 25,444 ha.

Evaluation of the germplasm bank

In each of the varietal improvement sites, CENICAÑA’s germplasm bank (approximately 1305 entries) were evaluated and characterised in two crops. The best varieties are identified based on production of cane, sucrose (% cane) and health, establishing elite groups of varieties that are used in crosses specific for each improvement site.

The design of the crosses is done using a tool that simultaneously takes into account all the traits with their respective restrictions, seeking complementarity and beginning by comparing the first variety of the group with the second and so on with the others. Then, the second variety is compared with those that follow and so on until finishing the comparisons between all the varieties in the group.

The basic principle of the algorithm consists of adding the values of the two varieties being considered for a given trait; if the sum is equal to or less than a given critical value, this process continues on to the second trait and so on until completing all the comparisons. If at any time the sum of a trait goes over the critical level, that cross will not be made.

Selection of clones

Every year, the selection process is begun with 120,000 seedlings that are distributed among the three selection sites. The best genotypes (clones and varieties) are selected in each of three stages and selection sites in accordance with the criteria or traits that the selected genotypes should have, referred to as *fundamental* (i.e. high content of total reducing sugars, high production of cane per ha, low flowering, and resistance to smut, rust and mosaic) and *desirable* (e.g. erect, high leaf fall, hairless leaf sheaths, resistance to yellow leaf virus, ratoon stunting disease, leaf scald and the yellow sugarcane aphid).

When the varieties have all the fundamental traits and some of the desirable ones, they continue the selection process through the three stages in each of the selection sites, until reaching the end of the process when 10–15 varieties are considered apt for establishing the regional trials located in the Semidry, Wet and Piedmont Zones, depending on their respective selection site.

Given that the conditions of these selection sites represent agroecological zones with different levels of productivity, specific objectives have been established as follows: (1) for the **Semidry zone**, varieties are selected that increase the minimum sucrose content by 5% and maintain the TCH in comparison with the check in the zone; (2) for the **Humid zone**, varieties are selected that increase the minimum sucrose content by 5% and increase the TCH by 15%; (3) for the **Piedmont zone**, varieties are selected that maintain the sucrose content and increase the TCH by 15%.
At the end of the process, approximately 9–9.5 years after having planted all the progeny of a given cross, some clones stand out for their productivity in TCH, sucrose (% cane) and TSH. Although the information that is available on these varieties comes from small plots, the results characterise the best varieties with respect to the check and orient the multiplication of the same for conducting final evaluations on the harvest, lifting, transportation and delivery of the cane, as well as factory processes.

**Multiplication and monitoring of the new varieties**

CENICAÑA’s agronomists, together with agronomists from the sugar mills and the growers, carry out the planting and multiplication of the new varieties, identifying the sites or agroecological zones where those new varieties have a higher level of productivity than the most cultivated variety in a given zone. Similarly, agroecological zones are identified where those varieties are equal to or have a lower level of productivity than the most cultivated variety in the same zone. In this way, the sites, agroecological zones or niches where the new varieties merit being planted and where not are determined. As a result of the selection, development, monitoring and multiplication of the varieties that are being carried out, there is a renovation of the varieties that the Colombian sugar sector has been planting for several years (see Table 1).

When comparing this information with that obtained in previous years, it can be seen that varieties V 71-51, PR 61-632, MZC 74-275, RD 75-11 and Co 421 have been decreasing their area planted, being replaced by new higher yielding varieties in the respective agroecological zone. The sugar sector’s dependency on CC 85-92 can also be observed in more than 69% of the zone, which is a risk from a sanitary standpoint given that it is not exempt from the influx of a new pest or disease that can cause losses in production as has occurred in other countries (Magarey et al., 2001).

<table>
<thead>
<tr>
<th>Varieties</th>
<th>Total (ha)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC 85-92</td>
<td>146 890</td>
<td>69.3</td>
</tr>
<tr>
<td>CC 84-75</td>
<td>27 330</td>
<td>12.9</td>
</tr>
<tr>
<td>V 71-51</td>
<td>8691</td>
<td>4.1</td>
</tr>
<tr>
<td>PR 61-632</td>
<td>3872</td>
<td>1.8</td>
</tr>
<tr>
<td>CC 93-3895</td>
<td>2203</td>
<td>1.0</td>
</tr>
<tr>
<td>MZC 74-275</td>
<td>1934</td>
<td>0.9</td>
</tr>
<tr>
<td>CC 93-4418</td>
<td>1477</td>
<td>0.7</td>
</tr>
<tr>
<td>RD 7511</td>
<td>1472</td>
<td>0.7</td>
</tr>
<tr>
<td>CC 92-2198</td>
<td>1441</td>
<td>0.7</td>
</tr>
<tr>
<td>CC 93-7510</td>
<td>991</td>
<td>0.5</td>
</tr>
<tr>
<td>CC 92-2804</td>
<td>780</td>
<td>0.4</td>
</tr>
<tr>
<td>CC 87-434</td>
<td>745</td>
<td>0.4</td>
</tr>
<tr>
<td>Co 421</td>
<td>728</td>
<td>0.3</td>
</tr>
<tr>
<td>CC 93-4181</td>
<td>650</td>
<td>0.3</td>
</tr>
<tr>
<td>CC 93-3826</td>
<td>593</td>
<td>0.3</td>
</tr>
<tr>
<td>CC 87-505</td>
<td>408</td>
<td>0.2</td>
</tr>
<tr>
<td>Others</td>
<td>5869</td>
<td>2.8</td>
</tr>
<tr>
<td>Renovation</td>
<td>5857</td>
<td>2.8</td>
</tr>
<tr>
<td>Total/ha</td>
<td>211 932</td>
<td>100.0</td>
</tr>
</tbody>
</table>

As a result of the multiplication and monitoring of the new varieties, data are given on the monitoring and multiplication of varieties CC 93-3895, CC 92-2804 and CC 93-4418, as an example of the three varieties with greatest growth in the industry during the past two years.
Variety CC 93-3895 has been harvested on 3857 ha in 51 agroecological zones, and has been equal to or higher in productivity (TCH, real factory yield and TSH) in 35 of them. Figure 1 shows the zones (10H2, 5H2, 7H0, 23H2, 29H1, 8H5, 6H2, 11H4, 6H4, 10H4 and 11H5) that cover 23 242 ha (11%) of the total area planted in cane, where CC 93-3895 is significantly higher in productivity (green colour) than the checks CC 85-92 and CC 84-75. Agroecological zones (15H0, 23H1, 11H1, 11H0, 15H1, 6H1, 5H4, 5H5, 30H2, 30H0, 5H3, 18H1, 31H0, 6H0, 22H0, 13H2, 18H3, 7H2, 10H5, 1H1, 8H3, 21H2, 6H3 and 8H2) where CC 93-3895 is equal in productivity (blue colour) to the checks cover 132 615 ha (65%) of the total area planted in cane. Those agroecological zones (30H1, 14H2, 11H3, 18H5, 14H1, 13H3, 18H2, 11H2, 24H2, 15H2, 8H4, 30H3, 23H4, 31H2, 17H5 and 18H0) where CC 93-3895 is lower in productivity (red colour) than the checks cover 33 446 ha (16%) of the total area planted in cane. The zone where the variety has been planted most is 6H1, where 954 ha have been harvested; the commercial results over the various crops are given in Table 2. Productivity has been stable over the four crops despite the decrease in the age of the cane at harvest.

Fig. 1—Agroecological zones where CC 93-3895 had a productivity (TSHM) higher (green), equal to (blue) or less (red) than the commercial varieties (CC 84-75 and CC 85-92) most planted historically at the same site.

<p>| Table 2—Commercial productivity of CC 93-3895 over five cuts in agroecological zone 6H1. |
|--------|--------|---------|------|------|--------|---|--------|---|</p>
<table>
<thead>
<tr>
<th>Cut</th>
<th>Area (ha)</th>
<th>Age at Cut (mo)</th>
<th>TCH</th>
<th>TCHM</th>
<th>Yield</th>
<th>TSHM</th>
<th>TSH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>528</td>
<td>14.3</td>
<td>138.0</td>
<td>9.7</td>
<td>12.6</td>
<td>1.216</td>
<td>17.3</td>
</tr>
<tr>
<td>2</td>
<td>327</td>
<td>13.1</td>
<td>129.1</td>
<td>9.9</td>
<td>12.3</td>
<td>1.207</td>
<td>15.8</td>
</tr>
<tr>
<td>3</td>
<td>79</td>
<td>12.5</td>
<td>122.1</td>
<td>9.8</td>
<td>12.1</td>
<td>1.172</td>
<td>14.7</td>
</tr>
<tr>
<td>4</td>
<td>17</td>
<td>12.2</td>
<td>100.4</td>
<td>8.1</td>
<td>12.3</td>
<td>1.009</td>
<td>12.5</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>12.9</td>
<td>77.8</td>
<td>6.0</td>
<td>14.5</td>
<td>0.876</td>
<td>11.3</td>
</tr>
</tbody>
</table>
Variety CC 92-2804 has been harvested on 1103 ha located in 24 agroecological zones, resulting in productivity equal to or higher than the checks CC 85-92 and CC 84-75 in 19 of them. Figure 2 shows the agroecological zones (32H2, 13H2, 15H2, 11H1, 15H1, 18H1, 1H1, 11H3, 6H3, 31H0, 22H1 and 27H1) which cover 56 278 ha (28%) of the land in cane, where CC 92-2804 has been significantly higher in productivity (green colour) than the checks. The agroecological zones (11H0, 6H1, 30H0, 11H2, 6H2, 7H0 and 10H4) where CC 92-2804 is equal in productivity (blue colour) to the checks, which represent 78 672 ha (39%) of the total area planted in cane. The agroecological zones (18H0, 23H2, 22H0, 15H0 and 26H1) where CC 92-2804 is lower in productivity (red colour) than the checks cover 8161 ha (4%) of the area planted in cane. The agroecological zone where the variety has been planted most is 6H1, where 388 ha have been harvested; the commercial results are shown in Table 3. Productivity has been quite stable over the seven crops, despite decreases in the age at harvest.

![Fig. 2—Agroecological zones where CC 92-2804 had a productivity (TSHM) higher (green), equal to (blue) or less (red) than the commercial varieties (CC 84-75 and CC 85-92) most planted historically at the same site.]

<table>
<thead>
<tr>
<th>Cut</th>
<th>Area (ha)</th>
<th>Age at Cut (mo)</th>
<th>TCH</th>
<th>TCHM</th>
<th>Yield</th>
<th>TSHM</th>
<th>TSH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>204</td>
<td>14.1</td>
<td>144</td>
<td>10.3</td>
<td>12.3</td>
<td>1.250</td>
<td>17.5</td>
</tr>
<tr>
<td>2</td>
<td>86</td>
<td>12.1</td>
<td>128</td>
<td>10.6</td>
<td>11.5</td>
<td>1.209</td>
<td>14.7</td>
</tr>
<tr>
<td>3</td>
<td>48</td>
<td>11.5</td>
<td>112</td>
<td>9.7</td>
<td>12.1</td>
<td>1.187</td>
<td>13.8</td>
</tr>
<tr>
<td>4</td>
<td>22</td>
<td>11.5</td>
<td>133</td>
<td>11.6</td>
<td>12.0</td>
<td>1.385</td>
<td>16.0</td>
</tr>
<tr>
<td>5</td>
<td>23</td>
<td>11.4</td>
<td>124</td>
<td>10.9</td>
<td>11.3</td>
<td>1.226</td>
<td>14.0</td>
</tr>
<tr>
<td>7</td>
<td>4</td>
<td>11.3</td>
<td>94</td>
<td>8.3</td>
<td>11.8</td>
<td>0.980</td>
<td>11.0</td>
</tr>
</tbody>
</table>

Variety CC 93-4418 has been harvested on 721 ha located in 17 agroecological zones, resulting equal to or higher in productivity than the checks CC 85-92 and CC 84-75 in 12 of the zones. Figure 3 shows the zones (30H2, 11H3, 6H1, 23H1, 11H2, 6H2 and 10H3) where CC 93-
CC 93-4418 was significantly higher in productivity (blue colour) than the checks, representing 72 286 ha (36%) of the total area planted in cane.

The zones (30H1, 11H0, 18H0, 11H1 and 22H0) where CC 93-4418 was equal in productivity (blue colour) to the checks represent 52 623 ha (26%) of the total area planted in cane. The zones (30H0, 18H1, 18H2, 26H1 and 6H0) where CC 93-4418 was lower in productivity (red colour) than the checks, cover 12 627 ha (6%) of the area planted in cane. The agroecological zone where the variety has been planted most is 11H0, where 216 ha have been harvested. The commercial results are given in Table 4. Productivity has been quite stable over all crops.

More precise and specific information by agroecological zone and other varieties in terms of productivity can be consulted on CENICAÑA’s Web page http://www.cenicana.org, Site-Specific Agriculture and Map Server, where one enters the property of the grower according to the sugar mill, lot and agroecological zone. With that information, you can construct the graphic representation of TCH, % sugar yield and TSH in so called isoproductivity curves for the agroecological zone of interest, using the same Map Server.

**Conclusions**

- Of the 16 varieties most cultivated by the Colombian sugar sector, 11 were developed by CENICAÑA and occupy 87% of the 211 932 ha planted.
• CC 85-92 continues to be the most widely planted although its percentage of participation in the sector last year did not increase, perhaps reaching its maximum % adoption in 2009.
• Varieties CC 93-3895, CC 93-4418 and CC 92-2804 have increased their area of planting the most in the last two years.
• By multiplying and monitoring CC 93-3895, CC 93-4418 and CC 92-2804 in the different planting sites, it was possible to prove the stability of their productivity over plant cane and several ratoons in the main agroecological zones where each of them is planted.

REFERENCES

DÉVELOPPEMENT DES VARIÉTÉS DE CANNE À SUCRE EN COLOMBIE POUR DES SITES SPÉCIFIQUES

Par
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MOTS CLÉS: Canne à Sucre, Variétés, Zones Agro-Écologiques, Sélection Ciblée.

Résumé
LA VARIÉTÉ de canne à sucre CC 85-92 est actuellement cultivée sur plus de 69% de la surface cannière en Colombie. C’est une situation inquiétante, du point de vue maladies, qui peuvent affecter la productivité de l’industrie. Ainsi, CENICAÑA a mis l’emphase sur une sélection qui cible des zones spécifiques de la production cannière. Après les essais régionaux, trois à cinq variétés émanant de chaque série, et dont leurs performances sont égales ou supérieures aux témoins, sont mises à la disposition des sucreries. Les variétés les plus en vue ont été soumises à un processus de multiplication et de contrôle afin de déterminer leur comportement dans diverses zones agro-climatiques dans le but de mettre à la disposition des planteurs celles qui sont adaptées à leurs conditions spécifiques. À ce jour, les variétés CC 92-2804, CC 93-3895 et CC 93-4418 se sont avérées les plus prometteuses. Dans la zone semi-aride, ces variétés ont une performance égale ou supérieure à celle de CC 85-92, ce qui est prometteuse pour l’industrie.
DESARROLLO DE VARIEDADES DE CAÑA DE AZÚCAR EN COLOMBIA PARA AGRICULTURA ESPECÍFICA POR SITIO

POR

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PALABRAS CLAVE: Variedades, Caña de Azúcar, Zonas Agroecológicas.

Resumen

El sector azucarero de Colombia tiene actualmente sembrada la CC 85-92 en más del 69% el área en caña de azúcar, situación que preocupa por la posibilidad de aparición de enfermedades que puedan afectar esa variedad y la industria. Por esa razón CENICAÑA adelanta de manera continua la obtención y selección de variedades con el enfoque de agricultura específica por sitio. Una vez finalizadas las pruebas regionales del proceso de selección, se entregan a los ingenios azucareros entre tres a cinco variedades por serie, las cuales igualan o superan al testigo empleado en dichas pruebas. Esas variedades consideradas promisorias deben seguir un proceso de multiplicación y seguimiento que determina su respuesta en las diferentes zonas agroecológicas. Cada día el número de variedades disponibles para los cultivadores es mayor con adaptación específica por sitio, buscando así aumentar la productividad del sector azucarero colombiano. En el proceso de multiplicación y seguimiento se destacan las variedades CC 92-2804, CC 93-3895 y CC 93-4418 entre otras, sembradas en campos comerciales de los diferentes ingenios azucareros. Los resultados indican que bajo las condiciones de la zona semiseca estas variedades se comportaron iguales o superiores a CC 85-92 en las zonas agroecológicas en donde se evaluaron y para la industria se constituyen en alternativas de siembra.
FAMILY SELECTION IMPROVES THE EFFICIENCY AND EFFECTIVENESS OF SELECTING ORIGINAL SEEDLINGS AND PARENTS

By

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KEYWORDS: Family Selection, Original Seedlings, Parental Selection.

Abstract

FAMILY selection has been used in several sugarcane breeding programs for many years, and has been shown to be superior to individual selection (also known as mass selection), in terms of gains from selection, resource efficiency, and cost of operation. Other breeding programs have expressed interest in family selection, but the technique has not been widely adopted for logistical reasons. Suggestions for overcoming the constraints to family selection are made. Family selection has also been shown to provide a superior method for estimating the breeding value of parent clones. Objective data on the performance of families provides invaluable information on the breeding performance of parent clones. Best Linear Unbiased Predictors (BLUPs) can be estimated for a range of traits from the results of family selection trials, and these are estimates of breeding value. In Australia, current research is aimed at improving the BLUP estimates by combining data across all selection programs, including family × environment interactions, and partitioning the genetic effects of each parent into additive and non-additive genetic effects.

Introduction

Family selection is used in the Australian and West Indian sugarcane breeding programs (Cox and Hogarth, 1993; Kennedy and Bellamy, 1997) and a modified version of family selection is used in Brazil (Bressiani et al., 2005), Colombia (Victoria, pers. comm.) and Argentina (Issa Joya, pers. comm.). The potential of family selection to be more efficient than individual selection at the original seedling stage of selection was first identified by Hogarth (1971). However, at that time, family plots had to be cut and weighed manually, and the cost was prohibitive.

When mobile weighing equipment was developed in Australia (Hogarth and Mullins, 1989), there was an opportunity to assess the benefits of family selection, and several research projects were conducted. There has also been interest in family selection in other countries such as Indonesia (Sukarso, 1986), Cuba (Ortiz and Cabellero, 1989), South Africa (Bond, 1989), Hawaii (Wu and Tew, 1989), Florida (Tai and Miller, 1989) and Louisiana (Chang and Milligan, 1992a, b). However, family selection has not been widely adopted and this may be because suitable harvesting and weighing equipment is not available. In this paper, we suggest methods that could be used to implement family selection without such equipment.

Cox and Hogarth (1993) showed that the most efficient method of family selection was likely to be based on the performance of families in replicated plant crop trials, followed by within-family selection in the first ratoon crop. McRae et al. (1993) and Cox et al. (1996) presented further
evidence that a combination of family and individual selection was likely to be more effective than family selection alone. Jackson et al. (1995) reviewed family selection in sugarcane and described its implementation in Australian regional selection programs. Family selection in Australia has proved to make better use of available resources and is less costly than individual selection in original seedlings.

Family selection is not just an effective method for selecting original seedlings; results from family selection trials can also be used to estimate the breeding value of the parent clones that produced the families. Stringer et al. (1996) and Barbosa et al. (2004, 2005) studied Best Linear Unbiased Predictors (BLUPs) of parental performance estimated from family selection trials. BLUPs are estimates of breeding value, which is the additive genetic component of the genotype. Stringer et al. (1996) showed that BLUPs were more effective than the empirical algorithm previously used by BSES (Hogarth and Skinner, 1986, 1987). Superior combinations were identified with less information so that a reduction in the generation interval is possible. Hence, since the early 1990s, BLUPs have been used to select parents for cross pollination in Australia. Until recently, data from each selection program were analysed separately and genotype×environment interaction for the families and parents was not considered. Current research by Atkin et al. (2009) and Atkin et al. (personal communication) is aimed at improving the breeding value estimates by combining data across all selection programs, including family×environment interactions and partitioning the genetic effects of each parent into additive and non-additive genetic effects.

In this paper, we will examine the theoretical basis for using family selection, examine the results of some family selection trials, suggest how family selection could be implemented without mobile weighing equipment, and discuss recent advances in the selection of parent clones and the adoption of a new genetic evaluation system.

**The theoretical basis for family selection**

At the original seedling stage of selection, each genotype is represented by only one plant. The phenotype of that plant depends on its genotypic value and the effect of the micro-environment in which the plant is grown. The environmental effect includes the effect of competition between plants, and Skinner (1961) showed that competition can have a highly significant effect on selection efficiency. The relative importance of the genotypic and environmental effects can be determined by conducting quantitative inheritance studies.

Skinner et al. (1987) showed that the degree of genetic determination (or heritability in the broad sense) for yield of cane at the original seedling stage was 0.17 or less (often much less) on an individual basis, but increased up to 0.75 on a family basis. This means that, on an individual basis, most of the variability among phenotypes is due to environmental effects. Consequently, selection for yield of cane on an individual basis will be largely ineffective in original seedlings. On the other hand, when families are weighed, most of the variability among families is due to genetic effects, so that the better families can be selected effectively.

When selected clones from the best families are planted into larger plots, the environmental effect is reduced relative to the genetic effect, and selection of individuals becomes more reliable.

It is important to recognise that most sugarcane traits are not inherited perfectly additively, especially cane yield, which is controlled about equally by additive and non-additive inheritance (see, for example, Hogarth (1987)). The implications of this are that parent clones can be selected for high sugar content or disease resistances based on the phenotypes of the parent clones but selection of parents for cane yield is much less reliable. As cane yield is a very important character, a strategy needs to be developed to maximise the chance of identifying families with high cane yield potential. The strategy developed in Australia is to plant as many experimental families as possible but relatively few seedlings are planted from each family (usually about 80 seedlings).
When the families are weighed in the plant crop, high yielding families are identified and, assuming their performance is satisfactory for other characters, these families are repeated in subsequent years in greater numbers. This maximises the chances of identifying high yielding families without wasting precious resources on planting a large number of seedlings from families that do not perform well.

**Results from family selection research trials**

McRae *et al.* (1993) found that both individual and family selection were effective in an experiment conducted in the Burdekin region of Australia. In this experiment, the trial was planted later than commercial planting and the plant crop was poorly grown. They found that selection of families from the well-grown ratoon crop was more effective than family selection in the poorly-grown plant crop.

Nevertheless, both individual and family selection from the plant crop were effective, and the best method was combined family and within-family selection. That is, individual genotypes are only selected in the best families identified by family performance in the plant crop. In view of the experimental results, families are now planted in the Burdekin at the same time as commercial planting so that ‘normal’ crops are grown.

Cox and Hogarth (1993) and Cox *et al.* (1996) studied combinations of family and within-family selection in two experiments at the Bundaberg Experiment Station in Australia. They obtained gains of 3.4% and 5.3% from individual selection and gains of 9.7% and 12.9% respectively from a combination of family and within-family selection. Thus, combined family and within-family selection was about 2.5 times better than individual selection alone.

**Family selection procedure**

Approximately 300 full-sib families are planted in each of the four regional selection programs in Australia. We aim to plant 80 seedlings per family in four replications of 20 seedlings. For each replicate, the seedlings are spaced at 50 cm in a single row of 11.4 m. If there are insufficient seedlings, there may be only two replicates from some families.

Typically, selection in family trials is a combination of family and within-family selection. Family selection is undertaken in the plant crop by assessing the performance of each family for cane yield, sugar and fibre content, and then concentrating selection efforts on the best performing families.

Only families in the top 40% undergo further selection in the ratoon crop, while poorer families are discarded as whole units. In addition, the numbers of individuals selected from within these top families depend on their performance in the plant crop. For example, 32 out of 80 individuals may be selected from the best 10% (i.e. 40% of individuals per family), 24 from the next 10%, 16 from the next 10%, and 8 from the next 10%. This means that the best families are selected at the highest rate.

**Family selection without harvesters or mobile weighing equipment**

A number of breeding programs worldwide have expressed interest in family selection, but have been unable to implement it due to problems with harvesting and weighing the plots. There are two possible methods to overcome this problem, depending on the resources available.

**Method when cane is cut manually**

If cane is cut manually and the cutters can be relied on to identify plots, it is suggested that families be planted in two replicates of 45 seedlings. However, three-row plots should be used rather than single-row plots. At harvest, the cane cutters can load the cane from the three–row plot of cane into one bundle for easy weighing. Weighing can be done either mechanically using a grab with scales or manually with a boom and grab. Before the advent of mechanical harvesting and weighing, replicated trials in Australia were cut manually and weighed by using a boom and grab.
Method when cane is cut mechanically

If cane is cut mechanically or the cane cutters can not be relied on to identify the ends of plots reliably, it is suggested that four replicates of single-row plots could be used as in Australia. To weigh the plots, the sampling method developed by Hogarth and Skinner (1967) could be used. Using this method, all the stalks in the plot are counted, and 40 stalks are cut from each plot. This 40-stalk sample would be weighed, and the plot weight estimated from the total number of stalks and the weight per stalk. By cutting 40 stalks from each plot, a path is cut through the trial allowing easy access of weighing equipment through the trial. A similar method was used in Australia for replicated trials when mechanical harvesters replaced manual cane cutters but before the development of mechanical weighing systems.

Estimation of breeding value of parents

Hogarth and Skinner (1986, 1987) developed an empirical method for evaluating the breeding potential of a parental clone based on agronomic performance called Net Merit Grade (NMG), disease resistance status, and selection rates from crosses involving that parent. This method was an improvement on the previous intuitive method, but the correlation between predicted performance and actual performance of crosses was only about 0.40–0.50. A major problem with the method was that the most important data about the performance of parent clones were the selection rates from families involving the parents. The most useful selection rate data were the rates from advanced stages of selection, so that it took many years (often at least 10 years) to obtain good data on new parent clones.

When Stringer et al. (1996) developed their method for estimating breeding values based on BLUPs, the correlation between predicted and actual performance improved. Furthermore, useful data were obtained as soon as the plant crop of family selection trials was harvested, so that useful parent clone performance data were available many years sooner. Cox and Stringer (1998) reported on BLUP estimates, based on NMG, for parents of families harvested from 1993 to 1996, which were correlated with actual family performance in 1995, 1996 and 1997. For 81-172 families with BLUP estimates for both parents, the correlations were 0.62–0.65 compared with 0.45–0.50 for the previous system for estimating breeding value. It should be emphasised that the BLUP estimates were often based on results of a single family selection trial whereas the previous breeding values were estimated from many years of selection data.

The NMG system for assessing clonal performance was described by Skinner (1967) and is based on tonnes cane per hectare (TCH), CCS (sugar content), fibre percent and visual appearance grade. Clones (or families) are compared with standard clones (or families), and a bonus is given if the CCS is higher than the standard CCS and a penalty is applied if fibre content is higher than the standards’ fibre. When BLUPs were first used to estimate breeding value of parent clones, the NMG of a family was calculated by comparing family performance with the mean of several standard (proven) families.

Problems with the NMG system

The problems with the NMG system and how to overcome them were detailed by Stringer et al. (2009). The issues will be described briefly in this paper.

The traditional genetic evaluation system relied on NMG and independent evaluation of clones for disease resistance and sugar quality. The system was inefficient because:

- Weightings of the different traits of importance in a cultivar did not reflect their true economic value. For example, NMG was highly correlated with TCH, so there was greater emphasis on selection for high TCH relative to high CCS. This was effective in maximising sugar yields, but high TCH clones have higher production and harvesting costs and produce a lower economic return for the whole industry than is possible with clones using optimal economic weightings for all traits.
• NMG did not incorporate disease resistances which were assessed independently for selection purposes. This is not as effective as index selection.

• NMG did not use inherent genetic correlations between traits and environments, even though many clones were tested at multiple sites and regions. An analysis that combines all trial results will produce a superior assessment of the true genetic value of a clone.

• NMG did not take account of variable data quality across trials and traits. BLUPs can overcome this problem.

• Breeding values predicted using BLUPs on data collected from family selection trials did not use pedigree information to calculate a NMG score.

The improved Genetic Evaluation System (GES)

The improved system is based on the theory of selection index (Hazel, 1943; Smith, 1936). A selection index considers all traits of economic importance and weights those traits with an appropriate economic weight. Economic weights were derived from a model developed by Wei et al. (2006) who obtained information from a consultative group consisting of a range of industry experts. Income and cost structures for the entire production, processing and marketing chain were used in the model by linking the incomes and costs with sugarcane traits. By changing one unit of a trait while holding other traits constant, the change in cost of producing one tonne of sugar became the economic weight of the trait. The economic importance of a disease was determined by its risk factor or potential damage. Cane yield loss was assumed to be the only damage caused by a disease with no effect on CCS.

It is also necessary to predict breeding values (BVs) of parent clones, which is achieved by using the statistical software ASReml (Gilmour et al., 2006). Until recently, the approach involved analysing each trial separately to identify outliers and site specific spatial variation as defined by Gilmour et al. (1997). Ten years of data were then combined with pedigree information on each parent within a region. A mixed model approach with a biparental genetic model (Henderson, 1984; Mrode, 2005) was used to obtain BLUPs for each parent. This approach was limited by not considering genotype×environment interaction for the families and parents. In a recent approach developed by Atkin et al. (2009) to use family data more efficiently, data from all four selection programs are now combined to exploit genetic variances and covariances between trials and regions (Atkin et al., personal communication). Additionally, the genetic effects of each parent are partitioned into additive and non-additive genetic effects (Costa e Silva et al., 2004). By using all available information from family trials and genetic correlations across regions, more reliable estimates of BV of parents are obtained.

To determine the best families, seven years’ data from each region are combined, excluding pedigree information. Data are analysed using a mixed model to partition individual family effects, and regions are assumed to be independent. BLUPs for each family within each region are estimated.

The Economic Breeding Value (EBV) of a parent clone is estimated from a selection index that incorporates the genetic effects and the economic weightings. The index is optimised to give estimates that have the most relevance for commercial production of sugarcane.

Conclusions

Family selection has been used in the Australian sugarcane breeding program for almost 20 years. There is a strong body of evidence to show that a combination of family and within-family selection is more effective (greater genetic gains) and more efficient than individual selection alone. In recent years, there have been major improvements to the way family selection is used in the BSES-CSIRO Joint Venture variety improvement program. We have replaced NMG with a new
selection index for estimating both the genetic value of families and the breeding value of parents, which uses economic weights of the various traits in a sugar production system and the best genetic estimates. This is part of an improved genetic evaluation system. We have also greatly improved methods of analysis by accounting for spatial variation, combining all data (over years and locations) and, for parents, partitioning the genetic effects into additive and non-additive genetic effects.

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LA SÉLECTION FAMILIALE AMÉLIORE L’ÉFFICIENCE ET L’EFFICACITÉ DE SÉLECTION DES PLANTULES ORIGINALES ET DES PARENTS

Par

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MOTS CLÉS: Sélection Familiale, Plantules Originales, Sélection Parentale.

Résumé

LA SÉLECTION familiale a été utilisée dans plusieurs programmes d’amélioration variétale depuis de nombreuses années, et s’est avérée supérieure à la sélection individuelle (également connue comme la sélection massale) en termes de gains en sélection, utilisation des ressources et coûts de l’opération. D’autres programmes d’amélioration variétale ont exprimé un intérêt pour la sélection familiale, mais la technique n’a pas été largement adoptée pour des raisons de logistiques. Des suggestions pour surmonter les contraintes de la sélection familiale sont faites. La sélection familiale a également démontré qu’elle peut fournir une méthode supérieure pour estimer la valeur génétique des parents. Les données objectives sur la performance des familles peuvent fournir des informations inestimables sur la performance des géniteurs. ‘Best Linear Unbiased Predictors’ (BLUP) peuvent être estimés pour une gamme de caractères à partir des résultats des essais de sélection familiale, et représentant des estimations de la valeur des parents. En Australie, la recherche actuelle a pour but d’améliorer les estimations du BLUP en combinant des données provenant de tous les programmes de sélection, y compris les interactions famille x environnement, et en décomposant des effets génétiques de chaque parent en effets génétiques additifs et non-additifs.
LA SELECCIÓN FAMILIAR MEJORA LA EFICIENCIA Y EFICACIA DE SELECCIÓN INICIAL DE LAS PROGENIES Y PROGENITORES

Por

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PALABRAS CLAVES: Selección Familiar, Progenies Iniciales, Selección Parental.

Resumen

LA SELECCIÓN familiar ha sido usada en varios programas de mejoramiento de caña de azúcar por varios años, mostrando ser mejor que la selección individual (conocida también como selección masal), en términos de ganancia por selección, eficiencia de uso de recursos y costos de operación. Aunque otros programas de mejoramiento han expresado interés por el uso de la selección familiar, esta técnica no ha sido usada mayormente por razones logísticas. Algunas sugerencias para superar los obstáculos del uso son sugeridas. La selección familiar también ha mostrado ser superior para estimar el valor genético de los parentales como una información objetiva sobre el comportamiento de las familias y la capacidad de cruzas de los clones parentales. Las mejores predicciones lineales no sesgadas (BLUPs) pueden ser estimadas para un rango de caracteres desde los resultados de los ensayos de selección familiar, que a su vez son los estimados del valor genético. En Australia, actualmente los experimentos están encaminados a mejorar los estimados de BLUP, combinado datos de todos los programas de selección, incluyendo las interacciones familia×ambiente, separando los efectos genéticos de cada progenitor entre los efectos aditivos y no-aditivos.
SUGARCANE SMUT IN AUSTRALIA: HISTORY, RESPONSE AND BREEDING STRATEGIES

By

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Abstract

ALTHOUGH sugarcane smut was first detected in the Ord River Irrigation Area of West Australia in 1998, the major sugarcane areas along the east coast of Queensland and northern New South Wales were not affected by the disease until it was found near Childers in June 2006. Since then there has been a rapid disease escalation and smut has now been found in most sugarcane regions of Queensland, but not in New South Wales. It is estimated that smut will be found on every farm in the Bundaberg-Childers, Mackay and Herbert regions in 2009 and economic losses will be recorded in some crops of susceptible varieties. This paper documents the development of the smut epidemic in Queensland, the strategy now in place to replace smut-susceptible varieties and the breeding approaches adopted pre- and post-incursion. A key feature was the screening of varieties, advanced clones and parents in Indonesia from 1998 onwards. Breeding strategies aim to minimise industry economic losses and maintain the rate of genetic gain. This should result in a high proportion of resistant and intermediate varieties being harvested by 2012 and the on-going release of new, highly productive, smut-resistant varieties to the Australian sugarcane industry.

Introduction

The Australian sugar industry is spread along a narrow 2500 km coastal strip of eastern Australia from Grafton in northern New South Wales (latitude 29.7°S) to Mossman in Queensland (latitude 16.5°S). The major cane growing regions are separated by cattle pasture or natural vegetation and these provide natural barriers to pest and disease spread. The Australian sugar industry has a well established internal quarantine system, supported by State Government legislation, and the alignment of quarantine boundaries with these natural barriers has limited the spread of serious pests and diseases such Fiji leaf gall, mosaic and cane weevil borers.

Sugarcane smut (Ustilago scitaminea Sydow syn. Sporisorium scitaminea) was found for the first time in Australia in July 1998 in the Ord River Irrigation Area (ORIA) of Western Australia (Riley et al., 1999), more than 2000 km from the main production areas on the east coast. Western Australian and the east coast sugarcane production areas are separated by tropical savannah with very sparse population. The Western Australian sugar industry had one small sugar mill with 4000 ha of commercial cane, and strict quarantine restrictions governed movement of machinery and cane from Western Australia to the eastern states to prevent human-assisted smut spread. The industry in Western Australia ceased production in 2007.

The smut resistance of Australian varieties was largely unknown in 1998 when smut was found in Western Australia. Limited information was available from overseas countries, but this was mainly for older varieties and there was disparity between ratings obtained from different countries. BSES established a testing program in Indonesia within months of the incursion in...
Western Australia (Croft et al. 2000) and information on the resistance of some Australian varieties became available from Western Australia (Engelke et al. 2001) with time.

Smut was found on the east coast of Australia in the variety Q205 in the Childers district in June 2006 (Croft et al., 2008b). This paper describes the spread of smut throughout Queensland, the response of the industry to the incursion, the impact of the disease on the industry and pre- and post-incursion strategies used in the BSES-CSIRO Variety Improvement program.

Smut spread within Queensland

Smut was found near Childers in June 2006 and intensive surveys showed the disease was already widespread in the Bundaberg-Childers region (Figure 1). Only a small number of farms were heavily infested and these were mainly in the Redridge area. The initial finding triggered a search for smut in other major cane growing regions. In November 2006, the disease was found in the Mackay region approximately 600 km north of Childers and, in December 2006, in the Ingham region a further 600 km north (Figure 2). In both the Mackay and Ingham regions, the disease was also well established and appeared to have been present for a number of years. It is possible that the three regions became infested at the same time, possibly from the same weather event that carried spores from the original source (Western Australia or overseas). The Mackay and Ingham findings meant there was no chance of containing smut within the southern region.

Fig. 1—Location of smut infested farms in the Bundaberg-Childers region of Queensland in October 2006. Infested farms are marked in red and the cane growing properties are highlighted in grey.
After the Ingham finding, nearly 12 months elapsed before the next two regional smut detections; these were in Maryborough, only a short distance south of Childers, and in Proserpine, a short distance north of Mackay (Figure 2). By the end of 2008, smut was found in all the remaining major cane growing regions. Smut detections in 2007 and 2008 probably represented spread from the three initially-infested regions. Only the most southerly sugar mills in the Australian industry remain free of smut (southern Queensland and New South Wales). However, it is highly probable that the disease is already present in some of these areas. Initial detections have been quickly followed by rapid local disease spread.

Spore trapping provided early warning of smut spread into new regions (Magarey et al., 2009a). Traps consistently detected smut spores 12–18 months before symptoms were detected in the field.

![Fig. 2—Smut findings in Queensland.](image)

**Spread within infested districts**

When smut was found in the Bundaberg-Childers region in 2006, susceptible varieties accounted for 78% of the crop with the two most widely grown varieties, Q188\(^A\) and Q205\(^A\), being rated susceptible.

An intensive surveillance program was conducted in the Bundaberg-Childers region between June-November 2006 (Croft et al., 2008b). A total of 8649 blocks on 1052 properties were inspected and 2.2% of the blocks and 7.4% of the properties inspected were smut-infested. The highest incidence was in the variety Q205\(^A\), with 8.3% of blocks infested. No disease was found in resistant crops, but some was found in crops of intermediate varieties. Trace back on one of the most heavily infested farms in the region suggested the disease had been present at least since the 2003/04 crop.
Monitoring of a series of farms within the district in 2007 and 2008 (Magarey et al. 2009b) provided information on disease spread; from this it was estimated that by mid-2009 all farms would become infested (Figure 3).

The planting of smut susceptible varieties was banned in the Bundaberg-Childers region in September 2006. Over 3750 t of seed cane of resistant varieties was transported 600–1200 km into the area to assist growers to transition to resistant varieties. The proportion of smut-susceptible varieties had fallen below 50% by 2009 and it is predicted that none will remain by 2011 or 2012.

Fig. 3—Estimated spread of smut in the Bundaberg-Childers region from 2004 to 2009 and the total area planted and the area of susceptible varieties. A field was considered to be infested if it had one smut whip.

Smut spread and variety replacement has progressed at similar rates in the Ingham and Mackay regions (Figure 4) where the most susceptible varieties are Q157, Q158, Q174\(^{A}\) and Q207\(^{B}\). Disease spread has been faster in the Ingham region relative to Bundaberg-Childers (Magarey et al., 2009b). Higher temperatures are likely to be favouring pathogen activity and varietal susceptibility.

Industry impact

Direct yield losses from smut have been minimal because the disease was detected before it had spread widely, smut response plans were quickly implemented in each region, smut resistant varieties were available from pre-emptive screening in Indonesia/Western Australia and growers have rapidly transitioned to resistant varieties.

Smut detection in a region was accompanied by virtually no further planting of susceptible varieties; this led to only isolated cases of primary infection (infection from infected seed cane) in susceptible crops–thus lowering direct yield losses.

Growers also have removed many smut-infested crops before disease levels have escalated, again reducing direct losses and slowing disease spread / buildup by minimising inoculum production.
Fig. 4—Estimated smut spread in the Mackay and Ingham regions (Inf) from 2004 to 2009 and the area of susceptible (S) varieties. A field was considered to be infested if it had one smut whip.

However, smut has had a significant financial impact via increased costs from premature ploughout of infested fields and shortened crop cycles. In most cases, growers have been able to plant resistant varieties with equal or better yield potential compared with the susceptible varieties they replaced. However, on occasions, a limited choice of resistant varieties has meant that some indirect losses have resulted.

The variety Q208$^b$ is high yielding, intermediate-resistant to smut and is likely to be the major variety in coming years. It has excellent yield and sugar content over a wide range of environments. A number of new high yielding smut resistant or intermediate varieties have been released since the smut incursion and these have good yield potential, including KQ228$^b$, Q232$^b$, Q238$^b$ and Q240$^b$.

**Smut strategies used in the BSES-CSIRO Variety Improvement program**

*Pre-incursion screening*

In preparation for a smut incursion, BSES negotiated a contract in 1997 with the Indonesian Sugar Research Institute to screen Australian varieties for resistance to the disease (Croft *et al.*, 2000). In 1998, another program was established by CSIRO, WA Agriculture and BSES to screen varieties for resistance in Western Australia (Engelke *et al.*, 2001). Initial studies showed that a high percentage of Australian varieties were susceptible to the disease.

Eleven smut trials were conducted in Indonesia from 1998–2008 (Croft *et al.*, 2008a). Varieties were shipped to Indonesia and planted in an open quarantine plot on Puteran Island, a site isolated from commercial sugarcane fields. After one year in quarantine, the varieties were planted in smut resistance trials on Madura Island to the east of Java. The standard smut dip inoculation method was used (Ferreira *et al.*, 1980). A set of 10–12 standard varieties was included in all trials. All trials consisted of four replicates with 10 two-eye-setts per replication, except for trials 1 and 2 which had three replicates of six two-eye-setts per replicate. The resistance ratings were based on the ISSCT scale of 1 to 9 (Hutchinson, 1970), where 1 = highly resistant and 9 = highly susceptible.
Eight smut resistance trials were conducted in the ORIA of Western Australia using the same techniques used in Indonesia, except that the trials consisted of only three replicates and four standard varieties.

Indonesian smut trials included a total of 2035 varieties with many varieties being tested in two or more trials. The distribution of resistance classes is shown in Figure 1. The predominantly Australian varieties screened in Indonesia have a strong bias towards susceptibility, with 66% of varieties in the susceptible range (rating 7–9). In contrast, in the ORIA only 43% of varieties were rated susceptible (Figure 5). Only varieties imported from overseas (with reputed smut resistance) and varieties from the Australian breeding programs that were already identified as intermediate to resistant in Indonesia were included in smut trials in the ORIA (except for the first two trials).

The proportion of the 2006 crop (tonnes harvested) produced by resistant, intermediate and susceptible varieties in each east-coast region is shown in Figure 6.

Susceptible varieties (rating 7–9) contributed more than 65% of the crop in all regions except the Burdekin and New South Wales, while in the Herbert the figure was more than 80%.

The Indonesian and ORIA screening trials provided information on varietal resistance allowing the east-coast industry to minimise losses from the smut incursion.

Smut-resistant varieties were rapidly propagated in all regions and planting of susceptible varieties was banned. Resistant or intermediate-resistant varieties such as Q177A, Q200A, Q208A, KQ228A and Q232A were propagated using traditional methods, spaced one-eye setts or tissue culture for rapid distribution to growers.

**Pre-incursion breeding strategy**

In 2001, when information became available from the Indonesian and ORIA resistance trials, a strategy was adopted that 50% of the crosses made in the BSES-CSIRO Variety Improvement Program would have an average smut rating for the parents (mid-parent rating) < 6.5.
When information was available for only one parent, further information was sourced for grandparents, providing a better estimate of the resistance of a cross. The initial data showed that, in 2000, only 20% of crosses had an intermediate smut mid-parent rating ($\geq 3.5$ and $< 6.5$) and there were virtually no resistant crosses ($< 3.5$) (Figure 7).

Fig. 6—Proportion of the 2006 crop (tonnes harvested) planted to smut-resistant, intermediate and susceptible varieties in the 6 production regions on the east coast of Australia.

Fig. 7—Mid-parent smut rating of crosses made in the BSES-CSIRO Variety Improvement Program 2000–2008 (Resistant = average of parent smut ratings $< 3.5$, intermediate $\geq 3.5$ and $< 6.5$ and susceptible $\geq 6.5$).
From 2000 to 2004 the proportion of crosses with intermediate mid-parent rating steadily increased as a result of this strategy but the proportion with resistant mid-parent rating remained at or below 10%. To improve the situation, one of the BSES photoperiod facilities was dedicated specifically to making smut-resistant crosses, supplementing the crosses made from field grown flowers. In 2004, the smut breeding strategy was again reviewed and modified to embrace a target of 25% crosses with mid-parent ratings in the resistant range and at least 25% in the intermediate range.

These goals were almost achieved in 2005 and were exceeded in 2006. After the 2006 smut incursion, only a small number of susceptible crosses with high breeding value were made, and in 2007 and 2008 approximately 10% of crosses were rated susceptible.

**Post-incursion screening**

BSES commenced screening trials in Bundaberg in August 2006. At this time, the quantity of available smut spores was limited so varieties were inoculated by painting a spore paste (0.1 g spores (approximately $1 \times 10^8$ spores)/mL in distilled water with 0.05% Tween 20) onto each bud. Whole stalks were used and the inoculated stalks were incubated overnight at 31°C and 100% relative humidity before planting into the field. The trials consisted of two replicates, and three stalks were planted per replication. Results were obtained for 1007 varieties and 10 standard varieties.

In 2007 and 2008, 1591 and 2257 varieties (respectively) were screened with the standard dip inoculation method. A similar number are planned for 2009. Four hundred tentative selections from stage 2 from each of the 4 regional selection programs, advanced selections from the final selection stage and parent clones were included in these trials. After dip inoculation, the inoculated one-eye setts were planted in trays of vermiculite and incubated in a chamber at 31°C for 7–10 days. These were transferred to a screen house for a further 7–10 days, potted out into peat pots and placed on outside benches for 3–6 weeks before being transplanted to the field.

Eight one-eye-setts from each variety were planted per replicate. Trials consisted of two or three replicates, depending on the selection stage of the test clones. Advanced parents or foreign clones were planted in three replicates, and clones from the early stages of the breeding programs (tentative selections from stage 2) were planted in two replicates. The plants were rated for percent smut infection and disease severity 3–4 months after transplanting, then ratoonied and rated again when the ratoon crop was 5–6 months old.

The 2007 and 2008 Bundaberg smut screening trials had high levels of smut infection; 54% of clones had greater than 30% smut infected plants in 2007 and 63% in 2008 (Figure 8). Further effort is required to reduce the proportion of smut susceptible clones in the Australian breeding program.

Following the smut incursion in 2006, a strategy was developed to minimise the impact of smut in the breeding program. The effective size of the program was dramatically reduced by the high frequency of smut susceptibility in breeding and selection populations; this inevitably impacted on the rate of genetic gain. In addition, many of the high breeding value parent varieties were susceptible to smut. To overcome this, a dual approach was adopted.

The smut strategy for the **Core** Variety Improvement Program is to only plant seedlings from crosses with a mid-parent rating <5. Similar strategies have been successfully followed for many years for other major diseases in Australia including Fiji leaf gall, leaf scald and pachymetra root rot.

The core program has been described elsewhere, but briefly it incorporates three selection stages, with family and individual selection in stage 1 (true seedlings) with stages 2 and 3 involving clonal selection. There are four regional programs.

However, a strategy needed to be developed to exploit high breeding value but smut-susceptible parents. This has been called the **SmutBuster** program and is basically designed to
select and exploit the low frequency of smut resistance in susceptible crosses (e.g. S*S, S*I). Each year approximately 40,000 seedlings from these crosses are planted at Bundaberg. This population is screened for smut resistance in a two-phase program, first as seedlings and then as clones.

Fig. 8—Frequency distribution of classes of percent smut infected plants for clones screened for smut resistance in Bundaberg in 2007 (1591 clones) and 2008 (2257 clones).

Post-incursion breeding strategy

There is no generally acceptable method for screening original seedlings. In 2006, original seedlings were planted directly to the field in November-December and a paste of smut spores was painted onto the buds of two decapitated standing stalks of each seedling in April 2007. This inoculation failed, with no smut infection developing. In 2007, seedlings at the 3–6 leaf stage, six weeks after transplanting, were trimmed to approximately 20–30 mm above the growing point and then sprayed with a suspension of approximately 1 x 10^6 viable smut spores per mL onto seedlings. The inoculated seedlings were placed in an incubation chamber at 31°C overnight and then planted to the field.

An experiment was established to examine three methods for inoculating original seedlings:

1. Dip inoculation of four week old seedlings. The seedlings were teased from the germination medium, washed in water and dipped in a spore suspension of 1 x 10^6 viable smut spores per mL for 10 min. The seedlings were then planted into potting mix in 90 mm peat pots and placed in an incubation chamber at 31°C overnight. The pots were planted to the field 4–6 weeks later.
2. Trimming and spray inoculation of seedlings at the 3–6 leaf stage, six weeks after transplanting from the germination trays. Plants were trimmed to approximately 20–30 mm above the growing point and then sprayed with a suspension of approximately 1 x 10^6 viable smut spores per mL onto seedlings before planting to the field.
3. Natural spread by planting the seedlings between smut-infected spreader rows.

In this experiment, 50 seedlings from 12 families with varying smut resistance were included in each treatment. An un-inoculated batch of seedlings was planted in a low smut risk area.
The un-inoculated seedlings were grown to maturity and then screened for smut resistance using the standard dip-inoculation method to estimate the resistance in each of the families.

The results indicate that dip inoculation when transplanting seedlings into peat pots is an effective method for screening true seedlings (Figure 9) and this practice was adopted in 2008. Natural spread was also effective but this method requires considerably more area to allow for spreader rows. The dip inoculation method allowed 23% of seedlings that develop smut whips to be discarded; however, the data from the control (34%) indicated 11% of susceptible clones may escape using this method. A second screening using normal clonal inoculation methods is required to adequately screen this population. About 10 000 seedlings with no smut and good visual appearance are selected and a 3-eye sett of each is cut. These are inoculated in family groups, incubated overnight at 31°C and planted to the field as spaced plants. Again, plants with no smut and good visual appearance are selected and about 2500 of these clones are propagated for stage 2 trials in each region.

![Fig. 9—Smut expression over time on sugarcane true seedlings inoculated using various methods. Clones (control) were planted separately and assessed once on plant crop. Error bars indicate standard error of means.](image)

The core program will provide 2500 clones with a high frequency of resistant and intermediate types that will be combined with the 2500 smut-resistant clones selected from more susceptible crosses, effectively doubling the size of the stage 2 clonal assessment trials (CAT).

This expanded program is critical to maintaining breeding progress for improved productivity, while ensuring that all new varieties have sufficient smut resistance. The program is summarised in Figure 10.

**Conclusions**

Sugarcane smut has spread rapidly throughout the Queensland sugarcane industry since it was first detected in 2006. The preparations for a smut incursion prior to its arrival allowed the Queensland and New South Wales industries to minimise losses and to quickly start the replacement of smut-susceptible varieties with resistant or intermediate-resistant varieties.

The BSES-CSIRO Variety Improvement Program commenced breeding for smut resistance in 2000 and the benefits of this pre-emptive breeding program, ultimately, will provide more highly-productive smut-resistant varieties and improved profitability of the Australian sugarcane industry.
Core program

- Based on smut-resistant parents (R*R/I)
- Stage 1–family and within family selection (4 regions)
- Stage 2–clonal assessment trials (2500 x 4 regions*)
  * Different clones

SmutBuster program

- Based on high breeding-value smut-susceptible parents (S*S/I)
- Stage 1–seedling and clonal screens for smut (40 000 x 1)
- Stage 2–clonal assessment trials (2500 x 4 regions**)
  ** Common clones

- 400 tentative selections (x4) screened for smut
- Stage 3 final assessment trials (150 x 4 regions)

Fig. 10—Outline of Core and SmutBuster programs.

Acknowledgements

The authors would like to acknowledge the contributions of many sugarcane industry groups and the Queensland Government Biosecurity section in the emergency response to sugarcane smut. Smut resistance trials in Indonesia were conducted by staff of the Indonesian Sugar Research Institute particularly Irawan and Ari Kristini. Smut trials in the ORIA involved staff of BSES, CSIRO and Western Australian Department of Agriculture particularly Tim Triglone, Phillip Jackson and Bill Webb. Smut trials in Bundaberg involved many BSES staff particularly Vicki Bardon, Dennis Taylor, Simon Manson, Rebecca James and George Bade. Smut resistance trials and studies on smut spread were partly funded by the Sugar Research and Development Corporation. The contribution of Primary Industries and Fisheries is also acknowledged.

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LE CHARBON EN AUSTRALIE: HISTORIQUE, DÉCISION ET CHOIX DES STRATÉGIES D’AMÉLIORATION GÉNÉTIQUE

Par

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MOTS CLÈS: Canne à Sucre, Charbon, Incursion, Criblage aux Maladies, Stratégies d’Hybridation.

Résumé

EL CARBÓN DE LA CAÑA DE AZÚCAR EN AUSTRALIA: HISTORIA, RESPUESTA Y ESTARATEGIAS DE MEJORAMIENTO GENÉTICO

Por
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PALABRAS CLAVE: Carbón de la Caña de Azúcar, Incursión, Evaluación de la Enfermedad, Estrategias de Fitomejoramiento.

Abstract
AUNQUE el carbón de la caña de azúcar fue detectado por primera vez en el área del Río Ord del Oeste de Australia en 1998, las principales aéreas de caña de azúcar a lo largo de la costa este de Queensland y Norte de New South Wales no fueron afectadas por la enfermedad hasta que fue encontrada cerca de Childers en Junio de 2006. Desde entonces, ha habido una rápida escalada de la enfermedad y el carbón se encuentra ahora en la mayoría de regiones cañeras de Queensland, pero no en New South Wales. Se estima que el carbón se encontrará en todas las unidades de producción en las regiones de Bundaberg-Childers, Mackay y Herbert en 2009, esto provocará pérdidas económicas en algunos campos con variedades susceptible. Este artículo documenta el desarrollo epidémico de la enfermedad en Queensland, la estrategia que hoy se dispone para reemplazar variedades susceptibles a carbón y los programas de fitomejoramiento adoptados en pre- y pos-entrada de la enfermedad. La clave del proceso fue el inicio de ensayos desde 1998 en adelante, para evaluación de variedades, clones avanzado y parentales en Indonesia. Las estrategias de mejoramiento buscan minimizar las pérdidas económicas de la industria y mantener la tasa de ganancias genéticas. Esto daría como resultado una alta proporción de variedades resistentes e intermedias cosechadas para el 2012 así como las nuevas variedades que están siendo entregadas que son altamente productivas y resistentes al carbón para la industria azucarera Australiana.
UTILISATION OF WILD CANES FROM CHINA

By

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KEYWORDS: Erianthus, Saccharum spontaneum, Introgression Breeding, DNA Markers.

Abstract

In 2002 a collaborative program of breeding and research was commenced, aiming to utilise wild germplasm from China for sugarcane improvement in both China and Australia. Some results and recommendations arising from this program to date are reported here. The program aimed to: 1. Characterise genetic diversity in Chinese S. spontaneum and Erianthus arundinaceus; 2. Conduct crossing between Chinese S. spontaneum and Erianthus spp. and sugarcane, and initial evaluation of the resulting progeny; 3. Assess if and how DNA markers can be used to identify genome regions of positive or negative value from wild clones, and to assist in programs aiming to introduce new genes from wild canes into commercial cultivars; 4. To quantify genotype × environment interactions between Australia and China. Results from the genetic diversity studies indicated a high level of genetic diversity in both S. spontaneum and Erianthus arundinaceus in China, and provide a basis for targeted sampling and use of this material in future breeding efforts or for core collections. Two hundred and two crosses from a range of S. spontaneum and Erianthus clones generated viable seeds, and 100 of these crosses have been verified (to date) using DNA markers as producing true hybrids. These results were significant in relation to Erianthus spp. in providing (to our knowledge) the first report of verified fertile Saccharum × Erianthus hybrids in the world, despite many past efforts. Several case study populations derived from S. spontaneum and Erianthus clones were used for Quantitative Trait loci (QTL) mapping. Several apparently important QTL for cane yield were identified from S. spontaneum. An approach to apply DNA markers in future introgression breeding in sugarcane is recommended, based on the results and experience obtained. Another significant result was the first (to our knowledge) documentation of genotype × country interactions. Somewhat surprisingly, moderate to high (>0.6) genetic correlations in performance of families and clones between trials in China and Australia were observed, despite some contrasting environmental and management conditions. This result supports ongoing collaboration between China and Australia via exchange of selection trial results and selected germplasm.

Introduction

Genetic improvement in most crop species has been characterised by incremental gains over time, with occasional larger ‘jumps’ in progress when some favourable new germplasm or genes are
found and used. In sugarcane, a major ‘jump’ arose with interspecific hybridisation in the early part of the 20th century when noble cane cultivars (Saccharum officinarum) were crossed with the wild species S. spontaneum and with hybrids derived from this wild species, by Indonesian and Indian breeders (Roach, 1989). Genotypes arising from these early programs (such as POJ2878, Co205) quickly became utilised not just as cultivars but also as parental material in sugarcane breeding programs world-wide. Following the success of these early interspecific hybridisations, sugarcane breeding programs have since largely concentrated on utilising clones derived from these early programs in further cycles of crossing and selection. However, this has contributed to a situation where most parent clones within sugarcane breeding programs around the world trace back to a relatively small number of key ancestors (Arceneaux, 1967; Roach, 1971). This small sampling of clones for breeding, combined with a perception among some sugarcane breeders of desirable traits in wild canes such as adaptation to environmental stresses, has led to ongoing interest from breeders in the introgression of new sources of germplasm (Roach, 1989).

Some serious attempts since the initial interspecific hybridisations to introgress new sources of germplasm have been made in several countries and are still ongoing. The focus in most has been on use of S. spontaneum but effort on other species including S. robustum in Hawaii (Heinz, 1967) and Miscanthus spp. in Taiwan (Lo et al., 1986) has also occurred. More recently, activity targeting Erianthus arundinaceus in several countries (eg. Miller and Tai, 1992; Legendre, 1989; Piperidis et al., 2000) has occurred, motivated by apparently desirable characters in this species such as vigour, drought tolerance, water logging tolerance, and disease resistance (personal communication with various breeders).

Generally, the procedure used in introgression breeding involves initial crossing between S. officinarum or commercial type parents and the wild species followed by several cycles of backcrossing to commercial sugarcane parents. However, the process of introgression breeding is generally very long, with each cycle of crossing and subsequent selection of progeny usually taking between six and eight years. Given that two or more backcrossing cycles are usually necessary to regain high levels of sucrose, it is clear that introgression breeding represents a long-term commitment. Further, commercial success has not always been achieved, with some major efforts (mostly not reported in the literature) not yet leading to released cultivars. The time and risk factors have acted to reduce the level of resources devoted in most sugarcane breeding programs to introgression breeding despite universal awareness of its potential value. Roach (1984, 1989), based partly on direct experience with the CSR program in Australia, listed several reasons for the failure of some efforts to provide more productive varieties. These reasons were largely related to inferior traits in the wild donor clones, and difficulties in selecting and combining the desirable portions of both the wild type and the recurrent parents during subsequent selection cycles. Another problem noted was the lack of cytological or genetic backup to confirm the hybrid nature of initial clones derived from interspecific hybridisation and selected for further crossing.

The surge in development and application of DNA markers in plant improvement programs starting in the 1980s potentially opens new horizons in crop improvement, and particularly introgression breeding. Two broad applications of DNA markers in relation to better utilisation of exotic germplasm can be readily identified. First, DNA markers may help determine genetic relationships among materials in collections, helping identify core sets of clones sampling major genetic diversity for breeding. Second, markers may be used to map quantitative trait loci (QTL) and facilitate identification and introgression of favourable genetic components from exotic germplasm.

Tanksley and Nelson (1996) and Tanksley and McCouch (1997) argue that, for most quantitative traits of commercial value, the phenotype of exotic genotypes will nearly always be dominated by the presence of unfavourable alleles, making identification of sources of potentially valuable genes using phenotype impossible for most quantitative traits. They suggested that the old
paradigm of utilising exotic germplasm involving ‘looking for the phenotype’ is being replaced by a new one involving ‘looking for the genes’ because of availability of QTL mapping.

In China, large scale collection of sugarcane related germplasm from the wild occurred during the 1980s and 90s. Many clones arising from these collections are maintained in the National sugarcane germplasm collection in Yunnan province (maintained by Yunnan Sugar Research Institute, YSRI) and in another collection in Hainan province (maintained by Guangzhou Sugar Industry Research Institute, GSIRI). Sugarcane breeders expect many of these clones to contain individual traits and genes of commercial value if they could be identified and recombined in other agronomically suitable genetic backgrounds. In 2002, breeders and scientists from China and Australia began a collaborative program designed to study and utilise wild germplasm from China, targeting eventual development of cultivars in both countries as the end goal. Of particular interest was to explore the role of DNA markers in assisting in introgression breeding in sugarcane.

This project had four main objectives as follows:

I. To characterise the genetic diversity available in the Chinese collections.

II. To generate progeny derived from Chinese *S. spontaneum* and *Erianthus* spp, and to commence field evaluation of these in China and Australia.

III. To determine if and how DNA markers could be used to help introgression breeding.

IV. To assess if selection in China could be used for Australia, and vice versa, through GE studies.

The aims of this paper are to summarise some progress with this collaborative program, some results to date, and possible future directions.

**Genetic diversity studies**

*S. spontaneum*

A diversity study was carried out on a collection of 443 clones of *S. spontaneum* sampled from across its geographic range and maintained in germplasm collections at BSES Ltd (Australia), Copersucar (Brazil), United States Department of Agriculture (USA) and the collections in China. 676 polymorphic AFLP markers were scored across all clones and the data subjected to principal component analysis (PCA). Two main clusters were identified with PCA which corresponded to clones collected from the tropics (mostly from southern India and SE Asia) and the sub-tropical (mostly northern India and China) regions. As seen in other *S. spontaneum* diversity studies, within each of these two clusters there was a tendency for clustering to be based on local geographic origin. Overall, an extremely high level of polymorphism was detected, with a large number of markers appearing in fewer than 10% of the clones, supporting the view that, of all the *Saccharum* species, *S. spontaneum* is the most diverse. While new sources of diversity were identified within the Chinese *S. spontaneum* collections, there was no obvious grouping of this material overall from other *S. spontaneum* clones collected in other parts of Asia.

*Erianthus*

A diversity study was also carried out with 220 clones of *Erianthus arundinaceus*, of which 123 clones were sourced from the National Nursery of Sugarcane Germplasm Resources (NNSGR) at YSRI in China, 74 clones from the BSES Ltd. Collection in Australia, and 23 clones taken from the collection of Copersucar in Brazil. Similar methods as used for the *S. spontaneum* study were applied. We found that *E. arundinaceus* from China was quite dissimilar and much more diverse than that collected from Indonesia (the latter comprised the other source of most clones studied). Within China, there was a major differentiation among material collected from eastern versus western China (ie. in contrast to differentiation on latitude). The results highlighted the uniqueness and importance of the genetic diversity within China for this species.
We also conducted research to help resolve the position of the species *Erianthus rockii*, a species unique to China and which is of interest in developing drought resistance, and which was used to produce hybrids with sugarcane during the collaborative program. The results suggested this species was distinct from other *Erianthus* and *Saccharum* species and was more similar to *Miscanthus* species. Details of this study were reported by Cai et al. (2005).

**Generation of progeny from *S. spontaneum* and *Erianthus***

Within the collaborative breeding program, 202 crosses were made by YSRI and GSIRI. Microsatellite markers that were highly polymorphic in sugarcane were used to check samples of progeny from crosses, following methods described by Cai et al. (2005). Samples of progeny from one hundred and forty-six crosses have been checked to date with DNA markers (example shown in Figure 1) with 100 showing at least some true hybrid progeny (Table 1). As expected, highest proportions of crosses delivering viable seed but ‘non-true progeny’ (arising from selfing of the female or pollen contamination) were those involving *Erianthus*, with crosses between sugarcane (*S. officinarum* or commercial cultivars) and *S. spontaneum* delivering true hybrids. Of particular significance and importance in this project was the verification of fertile hybrids derived from (*Saccharum × Erianthus*) × *Saccharum*. This result was the first validated backcross material from *Erianthus* in our experience, despite considerable efforts by other breeding programs in the past. This important result means that it should be possible to utilise the *Erianthus* genome in future sugarcane improvement.

![Fig. 1—Examples of checking progeny from crosses involving *Erianthus* using DNA markers. These are results from a single micro-satellite primer (one of three used routinely for checking), showing two groups of parents and progeny. The group on the left shows grandparent Guangzhe 14 (*S. officinarum*) which was crossed with YN95-34 (*Erianthus arundinaceus*) to produce YN2000-499, which in turn was crossed with YN2000-341 to produce putative BC1 progeny, a random sample of which is shown to the right. There is no evidence of bands characteristic of the *Erianthus* grandparent in YN2000-499, which appears to arise from selfing of Gangzhe 14, and therefore no evidence of BC1 progeny being derived from *Erianthus*. By contrast, the group on the right shows grandparent Luohouzhe (*S. officinarum*) which was crossed with Hainan92-84 (*E. arundinaceus*; note: this was mistakenly written as HN92-9 in the image above) to produce YN2000-117, which was crossed with commercial cultivar F172 to produce BC1 progeny, a sample of which are shown to the right. In YN2000-117, bands specific to the *Erianthus* parent are shown, and these are also apparent in the BC1 progeny, providing evidence of these being derived from *Erianthus*.](image-url)
Table 1—Numbers of crosses made for different types of crosses, showing numbers of crosses with validated true hybrids (ie. not arising from self pollination or pollen contamination).

‘Commercial’ refers to commercial cultivar or elite parent used in commercial breeding program.

<table>
<thead>
<tr>
<th>Type</th>
<th>Not examined to date</th>
<th>Tested and no true hybrids</th>
<th>True hybrids present</th>
<th>Total made</th>
</tr>
</thead>
<tbody>
<tr>
<td>S. officinarum × Erianthus arundinaceus</td>
<td>3</td>
<td>7</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>COMMERCIAL × E. arundinaceus</td>
<td>0</td>
<td>13</td>
<td>4</td>
<td>17</td>
</tr>
<tr>
<td>S. officinarum × E. rockii</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>COMMERCIAL × E. rockii</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>F1 E. arundinaceus × COMMERCIAL</td>
<td>5</td>
<td>8</td>
<td>6</td>
<td>19</td>
</tr>
<tr>
<td>BC1 E. arundinaceus × COMMERCIAL</td>
<td>35</td>
<td>9</td>
<td>24</td>
<td>68</td>
</tr>
<tr>
<td>COMMERCIAL × F1 E. rockii</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>S. officinarum × S. spontaneum</td>
<td>4</td>
<td>3</td>
<td>15</td>
<td>22</td>
</tr>
<tr>
<td>COMMERCIAL × S. spontaneum</td>
<td>0</td>
<td>0</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>COMMERCIAL × F1 S. spontaneum</td>
<td>6</td>
<td>5</td>
<td>14</td>
<td>25</td>
</tr>
<tr>
<td>Grand total</td>
<td>56</td>
<td>46</td>
<td>100</td>
<td>202</td>
</tr>
</tbody>
</table>

In all of the crosses made, half the seed was retained for use in China, and half imported into Australia following strict quarantine protocols. Clones generated from these crosses are now undergoing selection and use in further backcrosses to high-value parents in sugarcane breeding programs in both countries.

Targeted research trials were carried out on a range of progeny derived from S. spontaneum, and some methods and results in this study were reported in detail by Wang et al (2008). This study provided a preliminary evaluation of performance of a range of clones derived from diverse S. spontaneum clones when crossed with S. officinarum or sugarcane clones, as well as some basic statistical parameters that should guide the design of optimal early-phase selection among similar populations in the future.

Overall, the high genetic variation and broad-sense heritabilities (>0.7) observed among progeny for all traits suggests that large gains from selection in these populations could be easily achieved with limited replication (1 or 2 replicates) in small plot trials. For most biomass composition traits, the variation among the families comprised a substantial proportion (over 40%) of the genetic variation.

A selection system involving such initial selection of high-performing families for biomass composition traits, followed by selection among large populations within the best families, would represent an efficient method. Initial selection among families based on measuring a limited random sample of say 10 to 20 clones per family should be effective. For both cane yield and stalk biomass yield, the relatively smaller size of the among-family component suggests that family selection would be limited in effectiveness, and individual clonal selection within families would be important from early stages of selection.

Mid-parent values in an independent trial predicted biomass composition traits (brix, pol, fibre, dry matter %) among the progeny families reasonably well (generally r > 0.6), but less so for cane and biomass yield (0 < r < 0.4), suggesting the importance of non-additive genetic variance for yield traits. For biomass composition traits, moderate to high (>0.5) correlations were observed between the female (sugarcane or S. officinarum) parent and mean progeny performance, but not between the male (S. spontaneum) parent and progeny performance, emphasising the high importance of using high-performing female clones in crosses with S. spontaneum. For cane yield components of stalk number and stalk weight, correlations with progeny performance were high for both female and male parents.
Pol and purity levels in these progeny clones, as expected, were overall much lower than the commercial cultivars included in the trials for comparison, but some clones performing at levels similar to the commercial cultivars were also identified. For cane yield and biomass yields, clones with considerably higher biomass levels relative to commercial sugarcane were identified. However, as emphasised above, results relating to cane and biomass yields should be interpreted cautiously at this stage, since competition effects are important in the small plots used in this study, and further evaluation in large plots is required to substantiate these results. Nevertheless, the performance levels in biomass coupled with large predicted gains from selection suggest that some clones generated from crosses between sugarcane and *S. spontaneum* could offer opportunities for providing high yielding biomass crops. In addition, based on prior knowledge about the contribution of *S. spontaneum* to sugarcane breeding, it may be expected that strong ratooning ability and adaptation to a range of environmental stresses may be expected to be a feature of some first cross progeny involving *S. spontaneum*. These traits were not tested in the current study, but should be a priority for further evaluation.

**Use of DNA markers for introgression breeding**

A large effort was devoted toward determining if and how DNA markers may be used to identify favourable or unfavourable genes or QTL in exotic germplasm, which could be used in subsequent breeding and selection cycles. Scoring the AFLP gels for the large numbers of markers required for QTL mapping in sugarcane was extremely time consuming and prone to error variation, and any future marker work should benefit from a more automated marker system such as DArT (Jaccoud *et al.*, 2001). Several case study populations derived from *S. spontaneum* and *Erianthus arundinaceus* were studied. One population and some results are briefly described here to illustrate the approach used. This population was derived from the cross between ROC25 (a commercial cultivar bred in Taiwan province) × YN02-356. The latter clone was selected from the cross Co419 (Indian commercial cultivar and parent) × YN75-1-2 (a *S. spontaneum* clone collected from the wild in Yunnan province).

It was of particular interest to determine if favourable QTL could be identified from the wild *S. spontaneum* clone, which could then be selected for or against in further breeding cycles. A sample of 300 clones from this BC1 population was evaluated in a trial in Australia in very small plots, with each clone being planted into 4 replicates, arranged in a randomised complete block design with individual plots being a single row × 4 m long. Measurements were made on brix in juice, pol in juice, fibre, CCS, stalk weight, stalk number, cane yield (from product of prior two) and biomass yield. The population of clones was also screened with approximately 40 AFLP primer pairs and 12 SSR primer pairs in labs at YSRI and CSIRO.

Despite the relative sparseness of existing linkage maps, a number of important associations between markers and trait performance were apparent (Table 2). The effects for cane yield are particularly interesting, with these effects representing potentially important effects in a sugarcane breeding program. These results have provided further impetus to utilise selected clones from this population and linked markers for further breeding efforts, as discussed below.

<table>
<thead>
<tr>
<th>Marker</th>
<th>P value</th>
<th>Effect</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acctc58</td>
<td>&lt;0.00001</td>
<td>−39.4 t/ha cane yield</td>
<td>13</td>
</tr>
<tr>
<td>Acctc56</td>
<td>0.00002</td>
<td>+27.1 t/ha cane yield</td>
<td>6</td>
</tr>
<tr>
<td>Acctc51</td>
<td>0.0001</td>
<td>+24.4 t/ha cane yield</td>
<td>5</td>
</tr>
<tr>
<td>Cir56a</td>
<td>0.00017</td>
<td>+0.7 units brix</td>
<td>5</td>
</tr>
<tr>
<td>Acctc60</td>
<td>0.001</td>
<td>+0.6 units brix</td>
<td>4</td>
</tr>
<tr>
<td>Cir36d</td>
<td>0.001</td>
<td>+0.6 units brix</td>
<td>3</td>
</tr>
</tbody>
</table>
Genotype × environment interactions between countries

A common set of 26 clones was evaluated in multi-environment trials within both Australia and China (24 environments in Australia and 10 environments in China), with trial design and other procedures used described by Jackson et al. (2007).

Despite some major differences among trial environments between China and Australia for climate (especially temperature and solar radiation), and for some diseases, moderate to high genetic correlations between clone performance in China and Australia were observed for sugar content and cane yield. The average genetic correlation between environments in China versus Australia was 0.75 for CCS and 0.65 for cane yield. This is consistent also with results found with families derived from *S. spontaneum* where common families were evaluated in Australia and China and good genetic correlations between countries were observed (reported in Wang et al., 2008). These results are the first to our knowledge documenting genotype × country interactions. The results indicate that selection results in China are relevant to Australia and vice versa. Therefore, ongoing exchange of data, seed and selected clones could be mutually beneficial. This has led to a draft collaborative agreement between institutes in China and CSIRO/BSES for ongoing exchange of data and seed.

Further work and recommendations

Arising from the collaborative program of work, the following activities are planned or recommended:

- Further and more accurate evaluation of promising clones derived from *S. spontaneum* and *Erianthus* in both Australia and China, and further crossing of selected and verified (verified with DNA markers) clones to high value commercial parents.

- Initial selection among families and clones in the above program should be based on phenotype, without marker assisted selection. When a small number (2–3) of the best parents and bi-parental populations are identified, then QTL mapping should be done on one or more high value populations derived from new germplasm sources. Markers linked to favourable QTL introgressed into mainstream breeding programs may then be used in ongoing marker-assisted selection in materials along with other markers already used in the core program.

- There is interest in exploiting the genetic material generated in this collaborative project for emerging energy production systems in both countries. The relative value of fibre and other traits should be reviewed further with a view to informing breeding objectives. However, for the purposes of initial selection, a value of fibre relative to brix is suggested as 40% (ie. 1% increase in fibre content in fresh cane is worth 0.40 of the value of a 1% increase in CCS and brix content). This initial assumption is based on likely biofuel yields from sugars versus fibre and costs of conversion and assumed price parity between sugar and biofuel in the future. Other traits also need to be reviewed to determine optimal selection indices.

- To continue to exchange data and germplasm arising from the project efforts to date between China and Australia, in order to achieve mutual advantage from each other’s efforts in sugarcane breeding in the future.

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REFERENCES


**UTILISATION DES CANNES SAUVAGES PROVENANT DE CHINE**

Par

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**MOTS CLÉS:** Erianthus, Saccharum spontaneum, Hybriddation par Introgression, Marqueurs Moléculaires.

**Résumé**

recommandée. Un autre résultat significatif qui (à notre connaissance) est une première, est la documentation de l’interaction génotype x pays. Assez surprenant, des corrélations génétiques modérément élevées (>0.6) ont été obtenues entre la performance des familles et les clones entre les essais conduits en Chine et en Australie, en dépit des environnements divergents et une gestion différente. Ces résultats renforcent un besoin de collaboration continue entre la Chine et l’Australie par l’intermédiaire des échanges des résultats des essais de la sélection et du germoplasme.

UTILIZACIÓN DE CAÑAS SILVESTRES DE CHINA

Por

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PALABRAS CLAVES: Erianthus, Saccharum spontaneum,
Introgresión, Mejoramiento Genético, Marcadores ADN.

Resumen

UN PROGRAMA colaborativo de mejoramiento e investigación comenzó en el 2002, procurando utilizar germoplasma silvestre de China para mejorar las variedades de China y Australia. Algunos resultados y recomendaciones que salieron de este proyecto hasta hoy se reportan aquí: El programa tuvo como finalidad de: 1. Caracterizar la diversidad genética de las especies Chinas de S. spontaneum y Erianthus arundinaceus; 2. Conducir cruzas entre S. spontaneum and Erianthus spp. chinos y caña de azúcar cultivada así como una evaluación inicial de las progenies resultantes; 3. Evaluar si los marcadores del ADN pueden ser usados para identificar regiones del genoma de valor positivo o negativo de los clones silvestres, y asistir a los programas para introducir nuevos genes de las cañas silvestres a las cultivadas comercialmente; 4. Identificar las interacciones genotipo × ambiente entre Australia y China. Los estudios de diversidad genética mostraron un alto nivel de diversidad en S. spontaneum y Erianthus arundinaceus en China, y proveen las bases para identificar materiales claves y usar en cruzamientos futuros o formar colecciones núcleo. Se realizaron 202 cruzas de un rango de clones de S. spontaneum y Erianthus con semillas viable y 100 de estos cruzamientos se verificaron como híbridos verdaderos usando marcadores moleculares (hasta hoy). Estos resultados fueron significantes en relación a Erianthus spp. mostrando por primera vez la existencia de híbridos fértiles entre Saccharum × Erianthus comparados con otros esfuerzos del pasado. Varios estudios de caso de poblaciones derivadas de S. spontaneum y Erianthus fueron usadas para estudios y mapeo de locus de Caracteres Cuantitativos (QTLs). Aparentemente, varios QTL importantes parta producción de caña fueron identificados de S. spontaneum. Un método para aplicar marcadores moleculares en trabajos futuros de introgresión en caña de azúcar se recomienda basándose en las experiencias y resultados obtenidos. Otro resultado significante (de lo que conocemos) fue el primer reporte documentado sobre la interacción genotipo × ambiente. Sorpresivamente, las correlaciones genéticas fueron de moderado a alto (>0.6) en el comportamiento de las familias y clones entre los experimentos en China y Australia. Todo esto a pesar las condiciones contrates del ambiente y de manejo. Estos resultados soportan el trabajo colaborativo que está en marcha entre China y Australia a través de intercambio de germoplasma y resultados de los experimentos.
OPPORTUNITIES AND CHALLENGES FOR SUGARCANE BREEDING: A SUMMARY OF THE 9th ISSCT BREEDING AND GERMPLASM WORKSHOP

By

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KEYWORDS: Sugarcane Breeding, Biotechnology and Biomass, ISSCT Workshop.

Abstract

The 9th Sugarcane Breeding and Germplasm Workshop was held from 17 to 21 August 2009 at the Novotel Rockford Resort, Coral Coast Drive, Palm Cove, Cairns, Australia. The workshop was hosted by staff from the BSES Limited’s Meringa Experiment Station. BSES Limited, ISSCT, and the Sugar Research and Development Corporation of the Australian Government were sponsors for the workshop. The Breeding Workshop was attended by 70 delegates from different countries, and was distinguished by its scientific content, its impeccable organisation, and a great spirit of friendliness. Australia was well represented with a contingent of 20 breeders and researchers. Delegates from Argentina, Barbados, Brazil, China, Colombia, Ecuador, Fiji Islands, France, India, Indonesia, Japan, Mauritius, Reunion, South Africa, Sri Lanka, Thailand, Uganda, and USA attended. The presentations covered topics not only on breeding for sugar content but also biomass. There was an interesting analysis from an investor point of view on the advances in traditional plant breeding compared to the use of sugarcane transformation with novel genes. New molecular markers for mapping and genetic diversity studies and novel techniques for sugarcane biotechnology and bioenergy use also were discussed. Finally, an analysis on genetically modified (GM) sugarcane and associated biosafety risk was included. The Workshop demonstrated that traditional plant breeding and the biotechnology tools should work together in order to obtain rapid developments and increase production not only for sugar but also for bioenergy.

Introduction

The 9th Sugarcane Breeding and Germplasm Workshop was held from 17 to 21 August 2009 at the Novotel Rockford Resort, Coral Coast Drive, Palm Cove, Cairns, Australia. The Breeding Workshop was attended by 70 delegates from 19 different countries (Table 1), and was characterised by its excellent scientific content, impeccable organisation, and a great spirit of friendliness. The workshop theme was ‘Sugarcane Breeding: Opportunities and Challenges’. An important delegation of 20 breeders, pathologists, entomologists, biometricians and researchers in general from Australia was present. The Australian researchers showed a commitment for a cooperative research venture and its great achievements accomplished from several threats of devastating diseases to the applications of tools like the informatics and biotechnology to manage information and use of germplasm resources. There were 44 technical presentations during four
days of the workshop. The Wednesday visit to Meringa Station and the clear and practical demonstrations complemented the high scientific component of the Workshop.

Table 1—Country of origin and number of attendees of the 9th ISSCT Breeding and Germplasm Workshop.

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<td><strong>TOTAL</strong></td>
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Keynote talks and workshop topics
The 9th workshop had four keynote speakers covering topics:
1. ‘Future opportunities for sugarcane biomass use’ by Dr Les A. Edye, Principal Research Fellow, Queensland University of Technology, Brisbane.
2. ‘Sugarcane crop improvement—an R&D investors’ viewpoint’ by Dr Frikkie Botha, Executive Director, Sugar Research and Development Corporation, Brisbane.
3. ‘Global trends in sugarcane improvement—Syngenta’s view’ by Dr Manuel B. Sainz, Group Leader, Sugarcane Research, Syngenta Centre for Sugarcane Biofuels Development, Centre for Tropical Crops and Biocommodities, Queensland University of Technology, Brisbane, and
4. ‘Application of DArT technology and associated informatics to sugarcane crop improvement’ by Dr Andrzej Kilian, Director, Diversity Arrays Technology Pty Ltd, Yarralumla, Canberra, Australia.

The presentations were excellent and covered topics not only on breeding for sugar content but also biomass. The program for presentation was arranged in related groups of topics: 1) Bioenergy, 2) Molecular Breeding, 3) Physiology, 4) Biometrics, 5) Introgression, and 6) Crop Improvement grouped in five sessions.

Breeding for bioenergy
Many countries have initiated projects to exploit the potential of sugarcane biomass. The program of FAPESP-Brazil on bioenergy called BIOEN includes research on sugarcane breeding, ethanol production, and its impacts. BIOEN integrates comprehensive research on sugarcane and other plants. The Caribbean research is focusing on developing new cultivars that combine high sugar with high fibre content as multi-purpose energy canes, which will help to produce sugar as well as sustain energy production.

While traditional sugarcane may constitute the ideal energy cane in some scenarios, Type I (sugar + fibre) and Type II (fibre only) energy canes could have a broad-based impact in the national drive for developing sustainable energy technology. Future breeding of sugarcane for sugar plus energy production would be based on three objectives: 1) Economic analysis of different traits and determining optimal selection indices, 2) Optimal parental germplasm to use, 3) Target environments and selection systems.
Molecular breeding

This topic relates mainly to the use of molecular markers to help breeders to speed up the release of cultivars. Experiences from Australia on the use of molecular markers analysing the progress, lessons, challenges, and prospects, concluded that the impact of the use of molecular markers should be based on three strategies: 1) Association mapping in a broadly-based population of genotypes representing the core breeding program, 2) QTL mapping in one or several related crosses, and 3) QTL mapping in populations derived from wild canes. Results from association mapping indicated that markers correlated with cane yield, commercial cane sugar, and disease resistance can be easily found. A marker-assisted breeding program based on a narrowly based population may be effective for increasing rates of genetic gain compared with existing breeding programs. Comparative mapping of a sugarcane genetic map to the sorghum genome provides an important tool for identifying candidate genes underlying QTL regions that can lead to an acceleration of the breeding process for introgressing genes.

A long and constant research activity in CIRAD, France allowed characterisation of the Bru1 (brown rust resistance) locus and its distribution in sugarcane cultivars. Two PCR markers developed in the course of this mapping project in perfect linkage disequilibrium with Bru1 can be used to identify the presence of Bru1 in sugarcane cultivars. Identification of microsatellite markers associated with brown rust resistance in a sugarcane bi-parental cross is used in breeding programs of Brazil.

Target region amplification polymorphism can be used for studies on genetic variability among sugarcane genotypes. SSR loci have helped to identify the DNA profiling and genetic diversity of sugarcane germplasm. Identification of genes has allowed work on the molecular cloning and characterisation of cytosolic malate dehydrogenase gene SC cyMDH from sugarcane (*Saccharum officinarum* L.).

Molecular and in vitro technologies as adjuncts to conventional breeding are routinely used in South Africa. DNA fingerprinting is used to verify the identity of genotypes selected for bulking, while an in vitro micro-propagation protocol, based on the use of temporary immersion bioreactors, assists in both pathogen elimination and the mass propagation of selected genotypes.

Physiology and cane breeding

Sugarcane physiology related to plant breeding mainly covers photoperiod and flower induction. However, there is an increasing interest in studying the genetic control of some traits controlling sugarcane development and nutrient uptake. Assessing genetic variation in water use efficiency and resistance to water stress in sugarcane cultivars can help breeders to identify cultivars tolerant to water stress, providing direction for more focused and effective breeding and selection of improved cultivars. Efficient use of water is a major determinant of both irrigated and non-irrigated sugarcane production. However, improvement of water use efficiency and/or resistance to water stress has never been specifically targeted within sugarcane breeding programs elsewhere in the past. Breeding for high phosphorus use efficiency in sugarcane is of interest as low availability and high fixation of phosphorus are events frequently occurring either in acid or alkaline soils, which cover more than 30% of the world’s land area. Therefore, phosphorus deficiency is a primary constraint to sugarcane production in the tropics and subtropics. Comparing high and low phosphorus use efficiency (PUE) expression will be possible for screening of candidate genes associated with high PUE by molecular markers and comparative proteomics.

Management of flower initiation in tropical conditions has shown positive results. Modifications in the glasshouse on flowering and crossing efficiency need to be reviewed in a sub-tropical condition, where natural flowering is generally poor and inconsistent. No viable seed is produced under field conditions and breeders rely on artificial regimes of photoperiod and temperature to initiate and synchronise flowering for crossing and production of viable seed. Synchronisation of flowering between wild and hybrid cultivars is necessary for introgressing
genes. Phenology of sugarcane and *Erianthus arundinaceus* (Retz.) Jeswiet and development of a technique to control flowering time of *E. arundinaceus* is being studied in Ishigaki Island, Japan.

**Biometrical tools**

Biometrics has been and will be a major tool for crop improvement. There are several statistical methods to apply in sugarcane considering the different selection stages and applications of family or clonal selection systems. Methods of analysis for family and parent data have been developed for improving the efficiency of estimating breeding values of sugarcane parents to enable breeders to increase the rate of population improvement by better choice of parents and cross combinations. Optimal experimental design and analysis for sugarcane clonal trials with analytical methods have been developed that combine multi-site multi-harvest data in a single analysis. The advantage of such a single analysis is that genetic correlations of testing cultivars over sites and crops can be utilised and proper accounting for the residual correlations between crops at each site can made allowing more accurate selection decisions than the common practice of conducting separate analyses of individual trials and harvests.

An evaluation of new designs for the first clonal stage of selection at Mauritius Research Centre-MSIRI has been tested with an Augmented Latin Square (ALS) design superimposed on the conventional layout at the first clonal (2-m plot) stage in three sub-trials. The ALS design also accommodated a second control variety of wide adaptation with similar ripening pattern as the standard control.

Quantitative genetic analysis of progeny tests to improve selection and genetic gains in sugarcane breeding programs were introduced into the Canal Point sugarcane breeding program to evaluate the benefit of using a combination of between and within-family selection to improve genetic gains for sucrose content and cane tonnage and also as an aid to determine the sample size of the best families for advanced selection.

**Introgression in sugarcane**

Introgressing genes from wild species has been a common practice over the last 50 years of sugarcane germplasm enhancement program in Houma, Louisiana, USA, aiming to develop parental material with an expanded genetic base for the commercial breeding program. Clones with multiple genera and/or species in their background contain: *Erianthus brevibarbis* Michx. × *S. spontaneum* L.; *E. arundinaceus* × *Miscanthus* Anderss. spp.; *Miscanthus*. spp., *E. brevibarbis*, × *S. spontaneum*; *S. officinarum* L. × *S. spontaneum*; *E. arundinaceus* × *S. spontaneum*; and *M. sinensis* Anderss × *Saccharum* spp. hybrids. These wide crosses are being evaluated for cold tolerance, insect resistance, disease resistance, agronomic type, and yield characteristics.

Studies on morphological and genetic characters of the Thai *Erianthus* collection will help to identify materials for introgressing in a wide-crosses program. In China, studies on chromosome genetic analysis for the hybrid progenies of *S. officinarum* L. and *Erianthus arundinaceus* will help to identify the laws of chromosome transmission by chromosome number counts and karyotypic analysis in the hybrids and backcross progenies, and to get some cytological evidence of the use of *E. arundinaceus* in sugarcane breeding. Genetic diversity of sugarcane cultivars in mainland China is very low, as the pedigree analysis indicated using the core parental material which was descended from remote ancestral parents of two to four species of *S. officinarum*, *S. spontaneum*, *S. barberi* Jeswiet, and *S. robustum* Brandes and Jeswiet ex Grassl, with coancestry coefficients varying from 0.012 to 0.387.

**Sugarcane crop improvement**

A BSES-CSIRO joint venture variety improvement program for research and development (R&D), shows important innovations starting from the development of a web-based integrated database and crossing system (SPIDNet), use of mobile weighing equipment; routine use of SpectraCane, a NIR-based system for quality analysis using fibrated cane; a DNA fingerprinting-
based variety audit program for advanced clones and a molecular markers approach for marker assisted breeding. For example, the use of a centralised information management system like SPIDNet has produced benefits including data security, standardised data collection operations, fewer data errors, increased data availability, and the possibility of data exchange between BSES, CSIRO, and other industry partners.

The breeding objectives and its concept, construction, and implementation are based on each major production area with various steps: 1) examining the production system in each production area; 2) collecting all economic data related to each step in the production system; 3) assessing the impact of changes in performance for sugarcane traits on the economic data and 4) deriving economic importance or weight of each trait.

The foreign cultivars in the Australian sugar industry play an important role as parents in the development of new cultivars: 21 of the last 50 ‘Q’ cultivars have at least one foreign variety as a parent. Imported cultivars generally do not yield as well as locally-bred cultivars in selection trials. However, they are an important source of diversity and of new genes for resistance to diseases.

Up until the year 2000, orange rust was only a minor disease in Australia recognised by just a few disease specialists, but that changed when a new strain of the pathogen developed and rendered the widely grown cultivar Q124 susceptible. Fortunately, a high level of resistance was found in the germplasm making the selection of resistant cultivars easier. Disease control has been achieved using resistant cultivars and the disease no longer poses a threat to the Australian sugarcane industry.

A web-based variety management and information resource for the Australian sugar industry will help growers to better manage cultivars by providing specific recommendations and a broad range of information on cultivars, accessing the database in a grower-friendly format.

Parental selection for crosses is performed using the System of Information of Varieties – SIVAR in Colombia. The system designs crosses using trait values such as sucrose (cane %), stalk diameter, height, leaf shading (cover), flowering, tillering, lodging, stalk population, and resistance to smut, rust, and mosaic. The algorithm adds values for certain traits of both cultivars in comparison and if the sum is equal to or below a critical value, the process moves to the second trait and so on until all the comparisons are done for all traits.

If the sum of traits exceeds the critical level then the cross cannot be performed. Each descriptor is weighted according to its importance in the prototype of an ideal variety and this is multiplied by its descriptor to add the value of all weights to generate a value of merit of the variety.

There is a need to identify parental materials of high-sucrose for early harvesting in Ecuador; two groups (G1 and G2) were evaluated. These groups will be the basis to arrange crosses for high sucrose content.

In SASRI, research is being conducted collaboratively with the Sugar Milling Research Institute to determine whether near infra-red spectroscopy can satisfactorily predict colour and pith:fibre ratio of cultivars routinely processed in SASRI’s Mt. Edgecombe millroom.

A method that compares commercial productivity of new and older sugarcane cultivars is being used in Mauritius.

Plant breeders often are concerned about the commercial performance of their newly released cultivars relative to the older ones being replaced. Such a comparison is often difficult unless reliable and comparable commercial data are available.

Results were presented for a new multi-site selection network implemented in Réunion Island, which is designed to serve the very contrasting agronomic zones of the island.

Progress from breeding and variety selection programs in Argentina from 1989 until 2008 has shown a TCH increase of 5.3 t, TRS advanced by 4 kg per tonne milled, and TSH increased 0.85 t.
In China, over 90% of sugar produced is from sugarcane. The sugarcane growing areas are distributed mainly in the developing area of south-west China, where the economy is based on the sugar industry. Recently, sugarcane is grown for use as an ‘energy crop’.

As for all genetically modified crops, any GM sugarcane will have to undergo regulatory processes prior to commercial release, focused on safety to humans and the environment. Research provides baseline information for the decision making for the future deployment of GM sugarcane within the Australian regulatory context. Based on the Australian analysis, the information is applicable for sugarcane industries around the world.

Conclusions

Opportunities and challenges for sugarcane breeding remain intact as many new alternative breeding methods, molecular tools, and most importantly, the need for new cultivars of different usage are in demand. Traditional breeding still remains as the only practical system to release new cultivars, and the sugar industry needs trained crop improvement scientists to ensure future cane production. New genes from wild species are incorporated into the hybrid cultivars to ensure disease resistance and incorporate traits that are important in dry environments or heavy soils with low mineral contents. The 9th Breeding and Germplasm Workshop was a successful meeting in term of presenting a high level of knowledge to those delegates investing the time and money to attend. All the presentations were of scientific merit, with adequate time allowed for discussions.

Acknowledgement

We thank the BSES Limited’s management and staff for supporting the Workshop economically and technically. They shared their knowledge and scientific experiences in a series of presentations and their friendship shown during the Workshop and the social events were greatly appreciated by all participants. The work of the local Organising Committee: Dr. Nils Berding (BSES Limited, Chair), Dr. Michael Cox (BSES Limited), Dr. Phillip Jackson (CSIRO, Plant Industry), Mr. Ross McIntyre (BSES Limited) and Ms. Rhylee Pendrigh (BSES Limited), is gratefully acknowledged, as are the staff of the Meringa Experiment Station who provided excellent support for the field excursion.
LES OPPORTUNITÉS ET DÉFIS DE LA SÉLECTION AMÉLiorANTE DE LA CANNE À SUCRE: UN RÉSUMÉ DU 9ÈME ATELIER DE L’AMÉLIORATION GÉNÉTIQUE ET DU GERMOPLASME DE L’ISSCT

Par

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MOTS CLÉS: Amélioration Génétique de la Canne à Sucre, Biotechnologie et Biomasse, Atelier de l’ISSCT.

Résumé

Le 9ème atelier d’amélioration génétique de la canne à sucre et du germoplasme de l’ISSCT a eu lieu du 17 au 21 août 2009 au Novotel Rockford Resort, Coral Coast Drive, Palm Cove, Cairns, Australie. L’atelier s’est déroulé à la Station Expérimentale de Meringa du BSES Limited et parrainé par BSES Limited, ISSCT, ainsi que le Sugar Research and Development Corporation du gouvernement australien. Soixante-dix délégués de différents pays ont participé à l’atelier qui s’est distingué par son contenu scientifique, son organisation impeccable et l’esprit de camaraderie qui a régné. L’Australie était bien représentée par un contingent de 20 généticiens-sélectionneurs et des chercheurs. Des délégués étaient venus de l’Argentine, la Barbade, le Brésil, la Chine, la Colombie, l’Équateur, les Îles Fidji, la France, l’Inde, l’Indonésie, le Japon, Maurice, Réunion, Afrique du Sud, le Sri Lanka, la Thaïlande, l’Ouganda et les États Unis. Les présentations ont non-seulement couvert les thèmes concernant l’hybridation de la canne pour la richesse, mais aussi la biomasse. Une analyse intéressante a été présentée du point de vue d’un investisseur sur les avancées en sélection traditionnelle comparé à l’utilisation de la transformation génétique de la canne, avec des gènes nouveaux. Les nouveaux marqueurs moléculaires pour la cartographie du génome, la diversité génétique et les nouvelles techniques de biotechnologie pour la canne et l’utilisation de la bioénergie ont aussi été discutés. La canne génétiquement modifiée (GM) et les risques à la biosécurité ont également été abordés. L’atelier a démontré que l’hybridation traditionnelle et les outils de la biotechnologie devraient marcher de pair afin d’obtenir des développements rapides et augmenter la production, non seulement pour le sucre, mais aussi pour la bioénergie.
OPORTUNIDADES Y RETOS PARA EL MEJORAMIENTO DE LA
CAÑA DE AZÚCAR: UN RESUMEN DEL 9TH TALLER DE LA
ISSCT EN MEJORAMIENTO Y GERMOPLASMA

Por

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PALABRAS CLAVE: Mejoramiento de Caña de Azúcar,
Biotecnología y Biomasa, Taller de la ISSCT.

Resumen

El 9th Taller de mejoramiento y germoplasma de la ISSCT se realizó desde el 17 al 21 de agosto de
2009 en complejo hotelero Novotel Rockford Resort, Coral Coast Drive, Palm Cove, Cairns,
Australia. El Taller fue organizado por los investigadores de la estación Experimental Meringa de
BSES Limited. Los auspiciantes del evento fueron BSES Limited, ISSCT, y la Corporación de
Desarrollo para la Investigación Azucarera (SRDC) del Gobierno Australiano. Participaron en el
evento 70 delegados-investigadores de diferentes países, caracterizado por su alto nivel científico,
impecable organización y un enorme espíritu de amistad. Australia estuvo muy bien representada
con 20 mejoradores e investigadores. Hubieron delegados de Argentina, Barbados, Brasil, China,
Colombia, Ecuador, Islas Fiji, Francia, Indonesia, Japón, Mauritius, Reunion, Sur África, Sri Lanka,
Tailandia, Uganda y USA. Las presentaciones orales cubrieron tópicos no solamente de
mejoramiento para contenido de azúcar, sino también en biomasa. Hubo un importante análisis
desde el punto de vista de los inversores en investigación sobre los avances en el mejoramiento
tradicional comparado con los trabajos de transformación genética con genes novedosos. También
se discutieron nuevos marcadores moleculares para mapeo y estudios de diversidad genética, así
como nuevas técnicas en biotecnología de caña y el uso en bioenergía. Finalmente, se discutió sobre
los organismos genéticamente modificados (GM) y los aspectos de bioseguridad. El Taller, mostró
que el mejoramiento tradicional y las herramientas biotecnológicas deberían trabajar juntas para
obtener desarrollos rápidos no solamente en azúcar sino también en biomasa.
OVERVIEW OF SUGARCANE BREEDING IN MAINLAND CHINA

By

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KEYWORDS: Breeding, Sugar Production, Sugarcane, China.

Abstract

This paper briefly reviews the history of sugarcane breeding in mainland China, major sugarcane research institutes in different provinces, and the development and adoption of new varieties in the past 10 years. It also highlights important benefits and progress in introducing sugarcane varieties from overseas and Taiwan, China. Progress in utilising basic germplasm for sugarcane improvement in mainland China is also briefly reviewed. Challenges facing sugarcane breeding in China and potential ways to address these are proposed.

Introduction

China is currently the 3rd largest sugarcane producing country in the world, following Brazil and India. Sugarcane is mainly grown in south-western China. In the 2007–08 season, 1.47 million hectares of sugarcane was grown in China and produced 13.19 million tonnes of sugar.

Improvement of sugarcane varieties has played a critical role in the Chinese sugarcane industry. The central and local governments have therefore given a high priority to the program of sugarcane breeding, and sugarcane improvement through breeding has made considerable progress in recent years.

History of cane breeding in mainland China

Chinese people have cultivated sugarcane for more than 2000 years. In the early days, (before 1930) of sugar production in mainland China, the principal varieties were Bamboo Cane and Lu Cane, which were Saccharum sinense Roxb (Chen et al., 2003).

From 1932 to 1934, POJ2725, POJ2878 and POJ2883 were introduced from the Philippines, and Badila from Australia, but only POJ2878 and POJ2725 became major varieties for sugar production. F134 and Co419 (originally from India) were introduced to the mainland from Taiwan in 1947. F134 became the most popular variety in the sugarcane growing areas in mainland China until early 1980 (Peng et al., 1990).

In 1953, a sugarcane breeding station was established in Yachen Sanya (formerly known as Yaxian county), Hainan Island. It is located in a tropical region (18°27’N) and sugarcane can flower in the field (Figure 1). Sugarcane seeds from this station were sent to sugarcane research institutes in different provinces (Table 1). This station can make 1200 crosses from 1600 flowers every year. Besides this station, Ruili hybrid station can provide about 100 crosses. The number of seedlings is...
about 0.8 million over the country each year.

![Parental plots in the sugarcane breeding station in Yachen, Sanya Hainan province; (b) Crossing house at the same sugarcane breeding station.](image)

**Table 1**—The main sugarcane research institutes in different provinces in mainland China

<table>
<thead>
<tr>
<th>Institute Name</th>
<th>Location</th>
<th>Abbreviated Chinese name and prefix of varieties selected at each location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guangzhou Sugarcane Industry Research Institute (GSIRI)</td>
<td>Guangzhou, Guangdong</td>
<td>YueTang – YT, YueGan – YG</td>
</tr>
<tr>
<td>Sugarcane Breeding Station, GSIRI</td>
<td>Yacheng, Hainan</td>
<td>YaCheng – YC</td>
</tr>
<tr>
<td>Guangxi Sugarcane Research Institute, Guangxi Academy of Agricultural Science (GAAS)</td>
<td>Nanning, Guangxi</td>
<td>GuiTang – GT</td>
</tr>
<tr>
<td>Sugarcane Synthetic Research Institute, Fujian Agriculture and Forestry University (FAFU)</td>
<td>Fuzhou, Fujian</td>
<td>Funong – FN</td>
</tr>
<tr>
<td>Sugarcane Research Institute, Fujian Academy of Agricultural Science (FAAS)</td>
<td>Zhangzhou, Fujian</td>
<td>Mintang – MT</td>
</tr>
<tr>
<td>Sugarcane Research Institute, Yunnan Academy of Agricultural Science (YAAS)</td>
<td>Kalyun, Yunnan and Ruili, Yunnan</td>
<td>Yunzhe – YZ, YunRui – YR</td>
</tr>
<tr>
<td>Sugarcane Research Institute</td>
<td>Gangzhou, Jiangxi</td>
<td>Gangzhe – GZ</td>
</tr>
<tr>
<td>Sugarcane Industry Research Institute</td>
<td>Zhizong, Sichuan</td>
<td>Chuantang – CT</td>
</tr>
<tr>
<td>Economic Crop Research Institute, Guangdong Academy of Agricultural Science (GAAS)</td>
<td>Guangdong, Guangzhou</td>
<td>Yuenong – YN</td>
</tr>
</tbody>
</table>

Since the 1950s to 1999, more than 100 sugarcane varieties have been bred and released for commercial sugarcane production in mainland China. Of these GT11 (CP49-50 × Co419), YT57-423 (F108 × F134), YT63-237 (Co419 × CP33-310) and MT70-611 (CP49-50 × F134) have became dominant varieties for a period in different provinces (Lin *et al.*, 2004; Tan and He, 2004).
From 1999 to 2009, 42 new sugarcane varieties have been released for commercial sugarcane production (Table 2).

**Table 2**—New varieties released in recent 10 years and their parents.

<table>
<thead>
<tr>
<th>Variety name</th>
<th>Female parent</th>
<th>Male parent</th>
<th>Identified by</th>
<th>Released year</th>
</tr>
</thead>
<tbody>
<tr>
<td>GT91-116 (GT19)</td>
<td>ROC1</td>
<td>YC85-55</td>
<td>National</td>
<td>2005</td>
</tr>
<tr>
<td>GT93-103 (GT23)</td>
<td>ROC1</td>
<td>YC71-374</td>
<td>National</td>
<td>2005</td>
</tr>
<tr>
<td>GT94-116 (GT24)</td>
<td>GT71-5</td>
<td>YC84-153</td>
<td>National</td>
<td>2005</td>
</tr>
<tr>
<td>GT96-44 (GT25)</td>
<td>CP72-1210</td>
<td>YC71-374</td>
<td>National</td>
<td>2005</td>
</tr>
<tr>
<td>GT96-211 (GT26)</td>
<td>Pindar</td>
<td>GT11</td>
<td>National</td>
<td>2007</td>
</tr>
<tr>
<td>GT86-267 (GT16)</td>
<td>YT59-65</td>
<td>Ya72-399</td>
<td>National</td>
<td>1999</td>
</tr>
<tr>
<td>GT84-332 (GT15)</td>
<td>HN56-12</td>
<td>Neijian59-782</td>
<td>National</td>
<td>1999</td>
</tr>
<tr>
<td>GT89-5 (GT17)</td>
<td>GT11</td>
<td>YC62-40</td>
<td>National</td>
<td>1999</td>
</tr>
<tr>
<td>GT94-119 (GT21)</td>
<td>G275-65</td>
<td>YC71-374</td>
<td>National</td>
<td>2005</td>
</tr>
<tr>
<td>GT90-95 (GT18)</td>
<td>CP65-357</td>
<td>F172</td>
<td>Guangxi</td>
<td>2001</td>
</tr>
<tr>
<td>YT89-240 (YT48)</td>
<td>CP72-1210</td>
<td>GT11</td>
<td>National</td>
<td>2005</td>
</tr>
<tr>
<td>YT91-976 (YT49)</td>
<td>YN73-204</td>
<td>CP67-412</td>
<td>National</td>
<td>2005</td>
</tr>
<tr>
<td>YT91-1102 (YT51)</td>
<td>YN73-204</td>
<td>YT84-3</td>
<td>National</td>
<td>2007</td>
</tr>
<tr>
<td>YT93-159</td>
<td>YN73-204</td>
<td>CP72-1210</td>
<td>Guangdong</td>
<td>2001</td>
</tr>
<tr>
<td>YT85-177</td>
<td>YT57-423</td>
<td>CP57-614+CP72-1312</td>
<td>National</td>
<td>1999</td>
</tr>
<tr>
<td>YT96-835 (YT49)</td>
<td>Co419</td>
<td>ROC10</td>
<td>National</td>
<td>2007</td>
</tr>
<tr>
<td>YT96-86 (YT50)</td>
<td>YT85-177</td>
<td>Zang74-141</td>
<td>National</td>
<td>2007</td>
</tr>
<tr>
<td>FN91-3623</td>
<td>CP72-1210</td>
<td>GT11</td>
<td>National</td>
<td>2002</td>
</tr>
<tr>
<td>FN91-4621</td>
<td>CP72-1210</td>
<td>Zang74-141</td>
<td>National</td>
<td>2002</td>
</tr>
<tr>
<td>FN91-4710</td>
<td>CP72-1210</td>
<td>Ke5</td>
<td>Fujian</td>
<td>2004</td>
</tr>
<tr>
<td>FN94-0403</td>
<td>CP72-1210</td>
<td>MT69-263</td>
<td>National</td>
<td>2005</td>
</tr>
<tr>
<td>FN98-1103</td>
<td>C72-1210</td>
<td>Zang74-141</td>
<td>National</td>
<td>2009</td>
</tr>
<tr>
<td>FN95-1702</td>
<td>CP72-1210</td>
<td>YN73-204</td>
<td>National</td>
<td>2005</td>
</tr>
<tr>
<td>FN83-36</td>
<td>CP49-50</td>
<td>FN57-18</td>
<td>National</td>
<td>1999</td>
</tr>
<tr>
<td>FN81-745</td>
<td>YT59-65</td>
<td>CP36-105</td>
<td>National</td>
<td>1999</td>
</tr>
<tr>
<td>MT88-103</td>
<td>Co1001</td>
<td>YC82-96</td>
<td>National</td>
<td>1999</td>
</tr>
<tr>
<td>MT92-649</td>
<td>ROC1</td>
<td>Co1001</td>
<td>National</td>
<td>2005</td>
</tr>
<tr>
<td>MT86-2121</td>
<td>Q641</td>
<td>CP49-50</td>
<td>National</td>
<td>2005</td>
</tr>
<tr>
<td>MT92-505</td>
<td>Co1001</td>
<td>CP73-1547</td>
<td>national</td>
<td>2007</td>
</tr>
<tr>
<td>MT99-596</td>
<td>Co1001</td>
<td>YC73-226</td>
<td>National</td>
<td>2009</td>
</tr>
<tr>
<td>YZ85-151</td>
<td>Gang64-137</td>
<td>Chuang57-416</td>
<td>National</td>
<td>1999</td>
</tr>
<tr>
<td>YZ92-19</td>
<td>Gang64-137</td>
<td>CP67-412</td>
<td>National</td>
<td>2005</td>
</tr>
<tr>
<td>YZ89-351</td>
<td>YC82-96</td>
<td>GT11</td>
<td>National</td>
<td>2005</td>
</tr>
<tr>
<td>YZ94-375</td>
<td>CP72-1210</td>
<td>YC73-512</td>
<td>National</td>
<td>2007</td>
</tr>
<tr>
<td>YZ99-596</td>
<td>Co419</td>
<td>YC85-881</td>
<td>National</td>
<td>2009</td>
</tr>
</tbody>
</table>

* Variety identified by National means that the variety can be planted in main production provinces. Identified by one province means only can be grown in this province; before extending in other provinces, further testing may need to be done in those provinces.

Cane production and cane yield and quality have been improved very quickly in mainland China in the past 50 years. Cane production in mainland China has risen from 12.4 Mt in 1961 to over 97.5 Mt in 2008, while the harvested area has increased from less than 0.3 Mha to more than 1.5 Mha (Figure 2). Over the same period, cane yield has increased by about 40%, from under 50 t/ha to over 70 t/ha, representing an increase of 40% or an average 0.43 t/ha/year over 47 years. The average sucrose content, over this same period, has increased from under 13% to more than 14.5%,
with some varieties now providing an average over 16% (from October to April) (Figure 3 and Table 3). Success in the improvement of sucrose content is attributed at least partly to the use of introduced varieties with high sucrose, such as CP and ROC varieties, as parents.

**Fig. 2**—Cane yield and area in mainland China 1961–2008.

**Fig. 3**—Cane yield and sucrose content of sugar in mainland China.

### Table 3—Cane yield and sucrose content of new varieties in the sixth series of national evaluation trials.

<table>
<thead>
<tr>
<th>Varieties</th>
<th>Cane (t/ha)</th>
<th>Mean sucrose content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Means of February</td>
<td>Means of November–March</td>
</tr>
<tr>
<td>RB76-5418</td>
<td>123.92</td>
<td>15.33</td>
</tr>
<tr>
<td>FN02-3924</td>
<td>108.73</td>
<td>17.08</td>
</tr>
<tr>
<td>FN99-20169</td>
<td>124.96</td>
<td>16.18</td>
</tr>
<tr>
<td>GN99-519</td>
<td>117.05</td>
<td>15.87</td>
</tr>
<tr>
<td>GT98-296</td>
<td>116.15</td>
<td>16.50</td>
</tr>
<tr>
<td>GY6</td>
<td>128.23</td>
<td>15.29</td>
</tr>
<tr>
<td>MT95-261</td>
<td>122.57</td>
<td>15.57</td>
</tr>
<tr>
<td>MT96-6016</td>
<td>124.36</td>
<td>15.76</td>
</tr>
<tr>
<td>YT16</td>
<td>137.99</td>
<td>15.28</td>
</tr>
<tr>
<td>YT18</td>
<td>110.53</td>
<td>16.78</td>
</tr>
<tr>
<td>YZ99-91</td>
<td>108.62</td>
<td>16.53</td>
</tr>
<tr>
<td>CK1 (ROC16)</td>
<td>108.67</td>
<td>15.44</td>
</tr>
<tr>
<td>CK2 (ROC22)</td>
<td>116.21</td>
<td>15.60</td>
</tr>
</tbody>
</table>

**Sugarcane varieties introduced and used in mainland China**

A large number of overseas sugarcane varieties have been introduced into mainland China since 1978, such as the CP series of USA, Q series of Australia, PR series of Puerto Rico, RB series
of Brazil and ROC series of Taiwan, China. After quarantine, most of them have been used as parental clones in the breeding program.

The CP and ROC series (Wu et al., 2008), in particular, CP72-1210, CP84-1148, ROC1 and ROC10, were used most frequently.

Some introduced varieties were suitable for commercial production in some cane growing areas and adopted directly as varieties. After assessment trials, such clones have been released as commercial varieties.

The most important of these have been ROC10, ROC16 and ROC22 bred by Taiwan Sugarcane Research Institute in China, and introduced to mainland China in 1980–2000.

The planting area of these three clones has expanded continuously due to their high cane yield, high sucrose content and adaptation to a range of environmental conditions.

In the 2006–2007 season, these three clones accounted for 70 percent of the total planting area of mainland China.

**Basic hybridisation program in mainland China**

China is rich in sugarcane germplasm resources. Since the 1980s, Chinese sugarcane breeders have collected a large number of wild cane resources from different provinces and maintained most of these in the National Sugarcane Germplasm Nursery, Kaiyuan City, Yunnan province (Table 4).

Among them, *S. spontaneum* and *E. arundinaceus* are more prominent than other wild species.

<table>
<thead>
<tr>
<th>Genus</th>
<th>Species</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saccharum</td>
<td><em>S. officinarum</em></td>
<td>36</td>
</tr>
<tr>
<td></td>
<td><em>S. barberi</em></td>
<td>8</td>
</tr>
<tr>
<td></td>
<td><em>S. sinense</em></td>
<td>21</td>
</tr>
<tr>
<td></td>
<td><em>S. robustum</em></td>
<td>6</td>
</tr>
<tr>
<td></td>
<td><em>S. spontaneum</em></td>
<td>663</td>
</tr>
<tr>
<td></td>
<td>Landrace</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>Commercial varieties</td>
<td>1158</td>
</tr>
<tr>
<td>Erianthus</td>
<td><em>E. Arundinaceus</em></td>
<td>153</td>
</tr>
<tr>
<td></td>
<td><em>E. fulvus</em></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td><em>E. rockii</em></td>
<td>9</td>
</tr>
<tr>
<td>Narenga</td>
<td><em>N. porphyrocoma</em></td>
<td>13</td>
</tr>
<tr>
<td></td>
<td><em>N. fallax</em></td>
<td>2</td>
</tr>
<tr>
<td>Miscanthus</td>
<td><em>M. floridulus</em></td>
<td>10</td>
</tr>
<tr>
<td></td>
<td><em>M. sinensis</em></td>
<td>3</td>
</tr>
<tr>
<td>Imperata</td>
<td><em>I. cylindrica</em></td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>2163</td>
</tr>
</tbody>
</table>

As soon as the Sugarcane Breeding program was set up on Hainan Island, in 1953, Chinese sugarcane breeders began working on a basic hybridisation program by crossing the local *S. spontaneum* with Badila (*S. officinarum*).

This effort produced two high performing F1 hybrids; YC 58-43 and YC 58-47 (Deng et al., 2004), which in turn have produced 5 and 9 commercial varieties, respectively (Figure 4).

In recent years, Chinese sugarcane breeders have used *E. arundinaceus* to cross with *S. officinarum* in order to introduce the characteristics of resistance to disease and vigour in *E. arundinaceus* into sugarcane. Some promising clones have been bred from the cross between *Erianthus* and *Saccharum* (Figure 5).
Selection program in mainland China

The selection programs conducted in China are almost the same in all research institutes in mainland China. Clones are first tested in an experiment station at an institute for 5–6 years. This is followed by testing at multiple sites outside the original institute for 4–5 years. An example of such a program, conducted in Fujian province, is shown in Table 5.

In addition to selection schemes operated by each individual institute, in 1996, China began a new project to evaluate sugarcane varieties in a nationally coordinated series of trials.

The project was named the National Sugarcane Variety Cooperative Regional Test (NSVCRT), and was coordinated by Fujian Agriculture and Forestry University and supported by Crop Variety Examination and Approval Committee, Ministry of Agriculture in China.

Seven series of regional tests have been carried out and more than 110 varieties were assessed in the tests, of which 55 varieties have been approved and released.
Table 5—Sugarcane selection scheme in Sugarcane Synthetic Research Institute, Fujian Agriculture and Forestry University (FAFU).

<table>
<thead>
<tr>
<th>Year and stage</th>
<th>Site</th>
<th>Population size</th>
<th>Experimental design and selection criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y1 Single seedling</td>
<td>FAFU</td>
<td>200 crosses, 80,000 seedlings</td>
<td>Seedlings planted with 33 cm between plants and 100 cm between rows. Selection: vigour, stalk number, diameter, height and Brix</td>
</tr>
<tr>
<td>Y2 First clonal trial</td>
<td>FAFU</td>
<td>4000 – 5000 clones</td>
<td>Augmented design, 2.5 m long, 1.2 m row spacing, with commercial variety in every 30 rows. Selected in November. Plant cane only. Selection criteria are similar to Y1.</td>
</tr>
<tr>
<td>Y3 Second clonal trial</td>
<td>FAFU</td>
<td>300–500 clones</td>
<td>Augmented design, 3 row plots, 8 m long, 1.2 m row spacing, with commercial variety every 20 rows. Selection in plant cane. Visual screening for smut and mosaic resistance, juice analysis, estimating cane and sugar yield.</td>
</tr>
<tr>
<td>Y4 Preparation trial</td>
<td>FAFU</td>
<td>30–50 clones</td>
<td>RCB, 3-row plots, 3 replicates, 8 m long, 1.2 m row spacing. Selection in plant cane only, testing stalk numbers, diameter, height and yield, sucrose analysis, disease screening for smut and mosaic.</td>
</tr>
<tr>
<td>Y5-6 Comparative trial</td>
<td>FAFU</td>
<td>10–20 clones</td>
<td>5-row plots, 3 replicates, selection on 2 plant crops and one ratoon crop. Selection criteria same as in preparation trial.</td>
</tr>
<tr>
<td>Y7-9 Regional trial</td>
<td>8–12 sites</td>
<td>10–14 clones</td>
<td>5–6 row plots, 3–5 replications. Selection in 2 plant cane crops and one ratoon crop. Selection criteria same as in comparative trial.</td>
</tr>
<tr>
<td>Y9-11 Demonstration</td>
<td>8–12 sites</td>
<td>5–8 clones</td>
<td>10–20 row plot, unreplicated, 2 plant crops and one ratoon crop. Yield estimate and sucrose analysis</td>
</tr>
<tr>
<td>Y11-12 Approval</td>
<td>Approval</td>
<td>1–2 varieties</td>
<td>Approval by the National Sugarcane Variety Examination and Approval Committee for release</td>
</tr>
</tbody>
</table>

Issues in sugarcane breeding in mainland China

An issue of concern in China is that currently the planting areas of three ROC varieties accounted for 70% of the total sugarcane area in mainland China and exceeded 90% in Guangxi. The growing areas of new varieties bred in mainland China only accounted for 30%. Adaptability and yield stability of these newly bred varieties are commonly poorer than that of ROC series varieties. However, many of them have higher sucrose or higher TCH than the ROC series varieties.

It is considered greater progress will be made by increasing the scale of sugarcane breeding in China, which is limited by financial input by the Ministry of Agriculture and the Ministry of Finance of Chinese Government. Substantial financial support from the government for the long term should provide a golden chance for sugarcane improvement.

Acknowledgements

We acknowledge the following people for providing information used in this paper: Prof Chen Rukai from Sugarcane Synthetic Research Institute, FAFU; Mr. Deng Haihua, Guangzhou Sugarcane Industry Research Institute; Mr. Wu Caiven, Sugarcane Research Institute YAAS, Mr. Liu Shaomou, Sugarcane Breeding Station, GSIR, and Dr. Yang Rongzhong Guangxi Sugarcane Research Institute, GAAS. This study was partly supported by National Technical System for Sugarcane Industry and National 948 Key Project 2006–G37(2).

REFERENCES


 REGARD SUR L’AMÉLiorATION GÉNÉTIQUE DE LA CANNE À SUCRE EN CHINE CONTINENtALE

Par

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MOTS CLÉS: Amélioration Génétique, Production du Sucre, Canne à Sucre, Chine.

Résumé

CET ARTICLE passe en revue brièvement l’historique de l’hybridation de la canne à sucre en Chine continentale, les principales institutions de recherche dans les différentes provinces, le développement ainsi que l’adoption des nouvelles variétés de canne à sucre durant ces 10 dernières années. Il met en exergue les avantages et les progrès accomplis en introduisant des variétés de canne à sucre de l’étranger et de Taiwan, Chine. Le progrès accompli avec le matériel génétique de base est aussi brièvement examiné. Les défis auxquels l’amélioration génétique de la canne à sucre est confrontée, et les moyens potentiels de les aborder sont proposés.

VISIÓN GENERAL SOBRE MEJORAMIENTO DE CAÑA EN CHINA CONTINENTAL

Por

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PALABRAS CLAVES: Mejoramiento Genético, Producción de Azúcar, Caña de azúcar en China.

Resumen

ESTE artículo revisa rápidamente la historia del mejoramiento de caña en China continental, los principales institutos de investigación en las diferentes provincias y el desarrollo y adopción de Variedades en los últimos 10 años. También se destaca los importantes beneficios y progresos al introducir variedades desde otros países y Taiwán. Los progresos logrados al usar el germoplasma básico de China son también brevemente revisados. Futuros retos y caminos potenciales para trabajar en mejoramiento de caña en China también son analizados.
COMPARISON OF BIPARENTAL AND MELTING POT METHODS OF CROSSING SUGARCANE IN HAWAII

By

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(keywords: Biparental Crosses, Polycrosses, Specific Combining Ability.

Abstract

Sugarcane (Saccharum spp.) breeders at the Hawaiian Sugar Planters’ Association used biparental and melting pot (modified polycross) crossing methods concurrently from 1935 to 1985. While the annual effort expended to make biparental crosses exceeded the effort to make melting pot crosses over this 50-year period, annual viable seed yield from biparental crosses was usually less than 15% of that from melting pot crosses and, hence, the numbers of seedlings planted to the field from those crosses usually accounted for less than 20% of the total seedling population. In 1985, nine of the 10 sugarcane cultivars listed in Hawaii’s variety census originated from melting pot crosses; only one originated from a biparental cross. In the face of a shrinking sugar industry in Hawaii and a smaller work force in the breeding program, the decision was made in 1985 to rely primarily on melting pot crosses for the production of commercial cultivars. From 1985 to 2005, twelve additional clones that were bred prior to 1985 eventually attained ‘commercial cultivar’ status by exceeding 1% of the total cane growing area. All twelve originated from melting pot crosses. Over the 50-year period that the two crossing methods were used, the melting pot method proved to be more labour efficient and ultimately contributed more than the biparental crossing procedure toward the development of new commercial cultivars for the Hawaiian sugar industry. From 1985 forward, the biparental crossing method was used more for introgressing desired traits from exotic germplasm than for the development of commercial cultivars.

Introduction

Since 1935, sugarcane breeders at the Hawaiian Sugar Planters’ Association (HSPA) Experiment Station have employed the melting pot (MP) crossing method. This method was used sparingly until World War II. From 1942 to 1946, the MP method was used almost exclusively because of employee shortages at the Experiment Station; only 32 biparental (BP) crosses were made during this period.

After World War II, MP crossing remained an important method for developing new commercial cultivars in Hawaii. MP crossing was adopted at a few other sugarcane breeding stations around the world. However, it has not become the mainstay breeding procedure at most other breeding stations, including those in the USA.
The term ‘melting pot crossing,’ first coined by Dr. A. J. Mangelsdorf (1953), is a modified polycross. While the MP crossing method was being used in Hawaii, breeders working on other crops in the United States and Europe developed the polycross method for obtaining combining ability information in forage species. Tysdal et al. (1942) proposed the term ‘polycross’ to describe the progeny from a line that was subject to outcrossing with selected lines growing in the same nursery. A true polycross would consist of a collection of selected parents replicated in an isolated nursery in such a manner as to assure random inter-mating through open pollination. Ideally, every clone has an equal chance of being pollinated by every other clone in the polycross (Allard, 1960).

Thus, MP crossing, as conducted in Hawaii, does not constitute a true polycross because tassels from each clone may not be interspersed randomly, unequal numbers of flowers may be used from each clone, and tassels vary greatly in pollen production. Throughout this paper, the term ‘female’ refers to parents that shed little to no viable pollen at anthesis, and ‘male’ refers to parents that shed moderate to abundant viable pollen at anthesis at 20–30°C.

Warner (1953) stated that the MP crossing method was first explored in Hawaii with the object of evaluating the breeding value of a large number of parents at minimum expense. After several years of experience, a number of advantages to the use of the MP method were observed.

**Cost efficiency:** Considering labour, time, physical facilities, and space, the MP method produced a large number of seedlings at minimal cost. In Hawaii, establishing MP crosses is a one-day operation per crossing date. Stalks with tassels at early anthesis are cut and tagged in the field, then brought to the MP crossing shelters where they are interspersed. In contrast, erecting BP crosses is more labour-intensive and requires two days of activity per crossing date. The first day is spent recording numbers of tassels available by clone, determining the level of pollen production of individual parents by examining florets, then determining desired combinations based on individual pollen production and tassel availability. Relatively male-sterile parents (low- to non-pollen producers) are used as females, while moderate to abundant pollen producers are used as males. On the second day, tassels are collected and crosses are erected. In MP crossing, hundreds of tassels are compactly arranged in large shelters to achieve wide distribution of pollen shed from each tassel. In BP crossing, each cross must be kept isolated in order to prevent pollen contamination. Large cloth lanterns, first described by Skinner (1959) in Australia, were adopted on a large scale in Hawaii following the building of new crossing facilities at the HSPA Sugarcane Breeding Station in Maunawili Valley on Oahu 1975 in order to minimise cross contamination (Heinz and Osgood, 2009).

**Seed set:** Substantially more viable seeds per tassel are produced from the MP crosses than from the BP crosses. Low pollen viability of certain parents used as males and mating incompatibilities probably contribute to poor seed set in certain BP crosses. By contrast, a large amount of pollen is dispersed from a wide range of tassels in the MP crosses. Consequently, resulting recombinations obtained in MP crossing must be viewed as biased, rather than random.

**Genetic combinations:** With the same number of parents available, the potential number of possible parental combinations in MP crosses is exponentially greater than in BP crosses. To illustrate, assuming ten male-fertile tassels representing ten different parents were available, as many as 90 crosses \([n*(n-1)]\) or 45 unique genetic combinations \([n*(n-1)/2]\), discounting reciprocal crosses, are possible in a polycross arrangement. With the same number of male-fertile tassels and parents, only five BP crosses could be arranged in a manner that would assure cross fidelity.

The primary disadvantage of the MP crossing method is loss of pedigree information (inability to repeat crosses giving high selection rates, track inbreeding coefficients, determine
specific combining abilities, etc.; Stevenson, 1965) and hence, a theoretically lower level of parent selection efficiency (Empig et al., 1972), since half-sib rather than full-sib progeny are being assessed. Since the HSPA used both the BP and MP crossing methods concurrently for 50 years (discounting the World War II era), sufficient data have accumulated to assess the relative performance of the two procedures in Hawaii in relation to the production of commercial cultivars.

Breeding methodology

Melting pot crosses

The MP crosses, as arranged in Hawaii, consist of tassels from highly selected male-fertile cultivars, with more diverse, less highly selected male-sterile (female) cultivars (Warner, 1953). The number of tassels of individual parents in MP crosses is dependent on breeding interest, availability of tassels, and estimated pollen fertility. Seed is harvested from both male-fertile and male-sterile parents. In Hawaii, four principal MPs have evolved:

**General MP:** This was the largest and genetically most diverse MP. In addition to proven parents, recently tested clones with only limited yield information, as well as vigorous wild-derivative male-sterile (or sterilised) clones were included as parents.

**Leeward MP:** Clones adapted to irrigated leeward environments were included.

**Windward MP:** Clones adapted to rain-fed windward environments were included.

**Quality MP:** Relatively small numbers of elite clones and proven parents were included on the basis of exceptional individual and/or progeny performance in yield tests. Emphasis was placed on those clones with above-average sucrose content.

Special MP crosses were arranged for brief periods, often not greater than five consecutive years, to improve characteristics such as smut (Ustilago scitaminea H. & P. Sydow) resistance, drought tolerance, salt tolerance, and biomass potential. From 1974, wild-derivative MPs began to be made as an efficient method of incorporating into elite germplasm, genes from wild germplasm sources (Meyer and Heinz, 1975). Initially, both male (elite as female, wild derivative as male) and female (wild derivative as female, elite as male) wild-derivate MPs were made. Because very few wild-derivative clones were male sterile, the female wild-derivative MP was discontinued. The male wild-derivative MP was refined by forming three S. spontaneum L.-derivative MPs, namely Spont. 1, Spont. 2, and Spont. 3 (Meyer et al., 1982). These S. spontaneum-derivative MPs received tassels from first-generation (F₁), first backcross (BC₁), and second backcross (BC₂) male-derivative clones. Each derivative MP received tassels from at least 40 male sterile (or emasculated) commercial-type parents.

Biparental crosses

Until 1985, most BP crosses were commercial-type (Saccharum spp. hybrids) x commercial-type combinations. The traditional approach in making such combinations was to match elite parents with complementary traits (windward x leeward environment adaptation, high tonnage x high sucrose, etc.), until tassels were no longer available to make further crosses. A fully computer-driven procedure for determining usage of available tassels in BP combinations, such as the proven cross method used in Australia (Hogarth and Skinner, 1986), was never implemented in Hawaii, although data were electronically organised to assist breeders in arranging optimum crosses among available tassels.

Since 1985, BP crossing was principally used for population improvement, rather than the direct development of commercial cultivars. First-generation hybridisation between wild or foreign commercial clones × commercial-type clones, and early-generation backcrossing toward the commercial type was accomplished using the BP crossing method.
Results and discussion

The mean distribution of crosses made and seedlings produced at generational intervals from 1935 to 1985 is shown (Table 1).

<table>
<thead>
<tr>
<th>Decade</th>
<th>Biparental crosses</th>
<th>Melting pot crosses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. crosses (%)</td>
<td>No. seedlings (%)</td>
</tr>
<tr>
<td></td>
<td>Crosses (%)</td>
<td></td>
</tr>
<tr>
<td>1935–1944</td>
<td>35</td>
<td>44</td>
</tr>
<tr>
<td>1945–1954</td>
<td>14</td>
<td>21</td>
</tr>
<tr>
<td>1955–1964</td>
<td>13</td>
<td>18</td>
</tr>
<tr>
<td>1965–1974</td>
<td>11</td>
<td>16</td>
</tr>
<tr>
<td>1975–1984</td>
<td>14</td>
<td>19</td>
</tr>
<tr>
<td>Total</td>
<td>7 (15%)</td>
<td>39 (85%)</td>
</tr>
</tbody>
</table>

Since 1950, approximately 13% (520) BP and 87% (3480) MP crosses were made per year in spite of the greater effort that was required to erect BP crosses. The highest number of BP crosses achieved in Hawaii in a single year was 1200. The MP crosses could be placed directly from the field into the crossing house where they remained until seed harvest. By contrast, tassels in BP crosses had to be handled two additional times prior to placement in crossing lanterns in the BP crossing facility.

First, they were set in a staging area where the male and female parents were paired, and then they were moved to a temporary location where the desired male and female were secured together with the male tassels positioned approximately 20 cm higher than the female tassels, and the exposed anthers on the female tassels trimmed off.

Numbers of crosses per MP are determined by counting the number of parents used per crossing date, then summing over crossing dates. The General MP usually accounted for about 50–55% of the total MP crosses. Windward and Leeward MPs each accounted for approximately 15%, and the Quality MP for 5%.

Specialty MPs accounted for the remainder of crosses. Since 1972, following the formation of the first specialty MP (Smut Resistance MP), specialty MPs generally accounted for <5% of the total number of MP crosses arranged each year, thereafter.

The number of seedlings planted from BP and MP crosses does not necessarily correspond with the number of crosses arranged for or seed produced from each type of cross. Nearly all seed from BP and Quality MP crosses was planted, as was most seed from the Leeward and Windward MP crosses. By contrast, most seed from the General MP was not planted, unless there was a shortage of seed from other crosses.

During the 1977–1978 crossing season, BP and General MP crosses accounted for 12% and 51% of total crosses, respectively (Table 2). However, BP crosses accounted for nearly 18% of the seedling population, compared with only 32% for the General MP. Selection intensity from Stage 1 (seedling stage) to Stage 4 (preliminary yield testing) appeared to be nearly constant among MP and BP crosses.

From 1950 to 1980, approximately 15 to 20% of sugarcane seedlings planted each year originated from BP crosses. About 33% of all seedlings were from General MP crosses while roughly 50% of seedlings were from Leeward, Windward, Quality MP crosses, and special MP crosses.
Table 2—Number of clones selected from various MP and BP crosses in the 1977–1978 crossing season, a year representative of the 1965–1985 period.

<table>
<thead>
<tr>
<th>Cross</th>
<th>No. (%) of crosses</th>
<th>No. (%) of seedlings</th>
<th>No. (%) of Stage 4</th>
<th>Stage 4 seedling selection rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>BP</td>
<td>295 (11.7%)</td>
<td>196 448 (17.5%)</td>
<td>335 (16.8%)</td>
<td>0.17%</td>
</tr>
<tr>
<td>MP</td>
<td>2226 (88.3%)</td>
<td>925 416 (82.5%)</td>
<td>1655 (83.2%)</td>
<td>0.18%</td>
</tr>
<tr>
<td>General</td>
<td>1291 (51.2%)</td>
<td>360 168 (32.1%)</td>
<td>668 (33.5%)</td>
<td>0.19%</td>
</tr>
<tr>
<td>Quality</td>
<td>69 (2.7%)</td>
<td>116 480 (10.4%)</td>
<td>178 (8.9%)</td>
<td>0.15%</td>
</tr>
<tr>
<td>Lee</td>
<td>465 (18.4%)</td>
<td>258 848 (23.1%)</td>
<td>442 (22.2%)</td>
<td>0.17%</td>
</tr>
<tr>
<td>Wind</td>
<td>363 (14.4%)</td>
<td>153 280 (13.7%)</td>
<td>333 (16.7%)</td>
<td>0.22%</td>
</tr>
<tr>
<td>Other</td>
<td>38 (1.5%)</td>
<td>36 640 (3.3%)</td>
<td>34 (1.7%)</td>
<td>0.09%</td>
</tr>
<tr>
<td>Total</td>
<td>2521 (100%)</td>
<td>1 221 864 (100%)</td>
<td>1990 (100%)</td>
<td></td>
</tr>
</tbody>
</table>

Both BP and MP crosses played a significant role in the early production of commercial cultivars. Heinz and Osgood (2009) published a list of major cultivars in Hawaii (along with their parentages) in their review of the history of HSPA from 1946 through 1996. Three of the 22 cultivars they listed (H 37-1933, H 49-5, and H 59-3775) originated from BP crosses. All three pre-dated 1960. By 1985, nine of the 10 cultivars then being commercially grown in Hawaii (representing 97% of the area in sugarcane) were progeny of MP crosses. While there was a trend toward a decreased percentage of seedlings being planted from BP crosses, the proportion never dropped below 15%, between 1947 and 1975, and actually increased during the 1975 to 1985 decade. None of 21 cultivars that became commercial after H 59-3775 came from BP crosses. The under-representation of commercial cultivars originating from BP crosses, relative to the proportion of seedlings planted from 1955 to 1985, would suggest that the MP crosses were more effective in producing clones that would eventually gain commercial status.

In 1985, to investigate whether the lack of cultivars from BP crosses was likely to persist, the origin of clones having the greatest potential of attaining commercial status was investigated. Potential commercial clones were defined as those with a sugar yield per unit area matching or exceeding that of the major cultivar planted at the time in at least two advanced yield tests. Of the 51 clones that had commercial potential, only 4 (8%) were derived from BP crosses. Only eleven (22%) of the potential commercial clones were derived from General MP, suggesting that the more conservative and specialty (MPs) were the most efficient in producing commercial cultivars (70% of total).

Generating a large amount of viable seed from BP crosses is widely acknowledged as being more difficult than from MP crosses. However, the lower productivity of BP crosses, in proportion to their relative representation in the seedling population, is more difficult to explain. Although most parents used in BP crosses were selected primarily on the basis of their own performance, rather than proven parental performance, considerable effort went into making the most desirable combinations possible.

Unless the formation of BP crosses is based on the known specific combining abilities of the parents, the advantages associated with BP crosses are more than offset by their lower relative fertility. While BP crosses involving parents with known high specific combining ability will in theory produce more elite progeny and hence, have a higher probability of producing commercial cultivars, the challenge to the breeder is the time and effort needed to obtain and make use of specific combining ability data.
Results from a combining ability study in which families (rather than individual clones) were planted in yield test plots, indicated that non-additive genetic variation for sugar yield is important in cane harvested at 24 months (Wu and Tew, 1990). The performance of elite x elite crosses is difficult to predict without specific combining ability data. Perhaps the far greater number of combinations represented in MP crosses may be more advantageous than previously acknowledged, especially where selection and yield testing programs are designed to evaluate large numbers of seedlings. In spite of the shortfalls of MP crossing, results of this retrospective study suggest that MP crossing has been the more effective crossing method for exploiting specific combining ability in sugarcane.

Several efforts have been made to refine MP crossing. The most important recent improvement has been the effective hot water (50°C, 5 min) emasculation treatment prior to anthesis (Nagai, 1985). This treatment should permit increased flexibility in the selection of parents entering MPs. For example, lesser-tested new parents could be rendered male sterile before they are entered into an MP, in order to assure a high proportion of pollen from elite clones. With the ability to emasculate, it has become possible to use wild-derivative clones as female parents rather than as male parents, in the derivative polycross scheme. Physical separation of backcross generations during crossing also is no longer necessary. Results from the 1984–1985 crossing season indicate that, even though the emasculation procedure reduces female fertility, nearly half of all wild-derivative clones produced adequate seedlings for effective selection. This demonstrated that a large increase in the number of female parents could be achieved through the use of the emasculation procedure.

Presently, it is difficult to retrace the specific MP origins from which Hawaii’s commercially important sugarcane cultivars were derived. However, the MP origins of those cultivars deemed important enough to have been registered as commercial cultivars are known. Based on the MP origins of registered cultivars, it is apparent that the more elite MPs have been especially productive, particularly since 1960. Cultivars H 62-4671 (Heinz et al., 1979) and H 70-144 (Heinz et al., 1983) originated from the Quality MP. Cultivars H 65-7052 (Heinz et al., 1981a), the current leading cultivar in Hawaii, H 68-1158 (Heinz et al., 1981b), and H 73-7324 (Tew et al., 1992a), came from the Windward MP. Cultivar H 73-6110 (Heinz et al., 1984) came from the Leeward MP. Somewhat surprisingly, three cultivars, H 74-1715 (Tew et al., 1988), H 74-4527 (Tew et al., 1992b), and H 78-4153 (Wu, 2003) originated from a special MP set up shortly after the discovery of smut in Hawaii that involved smut-resistant parents. This MP was referred to as the Smut MP (1972–1978). Cultivar H 78-292 (Tew et al., 1992c) is the only registered cultivar of recent vintage that originated from the General MP.

Conclusions and recommendations

The MP crossing method has been more productive than the BP crossing procedure in the development of new commercial cultivars for the Hawaiian sugar industry. From 1955 to 1985, only one commercially important cultivar was produced from BP crossing compared with 26 cultivars from MP crossing. Without the availability of specific combining ability data, the only demonstrated advantage BP crossing has over MP crossing is the preservation of ancestral information. Obtaining specific combining ability data in Hawaii is difficult because the crop is grown to an average of 24 months of age. After eight months’ age, the crop forms an entangled mat of cane, precluding effective visual evaluation in small plots. The correlation between cane volume at eight months and cane weight at 24 months is negligible (Wu, 1983). Entry of full-sib families, rather than individuals, into yield tests may allow a reliable measure of specific combining ability at harvest (Wu and Tew, 1990), but this procedure is so costly and time consuming as to be impractical. Limited BP crossing for specific purposes, such as conducting genetic studies, or evaluation of specific combining ability among commercially important cultivars, for example, may be justified.
After 2010, there will only be one plantation remaining in Hawaii, namely Hawaii Commercial and Sugar Company (HC&S) on the Island of Maui. It is therefore unlikely that the remaining breeding program, tailored to one plantation’s needs, will accommodate more than one MP in the future. In most breeding programs around the world, including Hawaii’s, the turnover rate of parents tends to be conservative; the majority of parents used in one year will be used the following year.

We recommend the continued inclusion of recently yield-tested clones as experimental parents in this MP. Parents with only preliminary yield data could be emasculated and older proven parents be used as the primary pollen source. This modification should result in an increase in the mean performance of progeny from this MP and allow a more meaningful comparison of the relative performance of the newer clones as parents, since the pollen source is controlled.

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Acknowledgement is given to: Dr Albert J. Mangelsdorf, whose sugarcane breeding career at HSPA spanned from 1926 to 1961; Dr John N. Warner, whose breeding career at HSPA spanned from 1940 to 1965, with breaks to serve during World War II, and to obtain a PhD degree (HSPA-paid leave); and Dr Don J Heinz, whose breeding, administrative, and consulting career at HSPA spanned from 1961 to 1995, for the important contributions that they made toward the improvement of the HSPA breeding and selection program during the course of their careers.

REFERENCES


COMPARAISON DES MÉTHODES DE CROISEMENT BI-PARENTAL ET DU CREUSET POUR LA CANNE À SUCRE À HAWAÏ

Par

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MOTS CLÉS: Croisements Bi-Parentaux, Polycroisements, Aptitude Spécifique à la Combinaison.

Résumé

Les généticiens-sélectionneurs de la canne à sucre (Saccharum spp.) au Hawaiian Sugar Planters’ Association avaient recours aux méthodes de croisement bi-parental et du creuset (polycroisements modifiés) de 1935 à 1985. Alors que l’effort annuel déployé à entreprendre les croisements bi-parentaux excédait celui du creuset pendant cette période de 50 ans, la viabilité des graines issus des croisements bi-parentaux était de 15% inférieure à celle du creuset. Par conséquent, le nombre de plantules provenant de ce type de croisement était généralement inférieur de 20% à la population totale des plantules. En 1985, neuf des 10 cultivars de la canne à sucre du recensement variétal de Hawaï provenaient des polycroisements et un seul cultivar provenait des

**COMPARACIÓN DE LOS MÉTODOS DE CRUZAMIENTOS BIPARENTALES Y CRUZAS MÚLTIPLES (POLICRUZAMIENTO MODIFICADO) EN CAÑA DE AZÚCAR EN HAWAI**

Por

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PALABRAS CLAVE: Cruzas Biparentales, Policruzamientos, Habilidad Combinatoria Específica.

Resumen

Los mejoradores de caña de azúcar (Saccharum spp.) en la Asociación de Cultivadores de Caña Hawaianos, usaron los métodos de cruzamientos biparentales y la fusión de varios parentales o cruzas múltiples (policruzamiento modificado, ‘melting pot’) en forma concurrente desde 1935 hasta 1985. Mientras los esfuerzos usados para hacer cruzamientos biparentales excedieron a cruzas múltiples durante un periodo de 50 años, la producción de semillas viables anualmente de los biparentales usualmente fueron menores al 15% comparados al método de cruzas múltiples, por esta razón el número de plántulas sembradas en el campo de estos cruzamientos generalmente fueron 20% menos en el total de la población de plántulas. En 1985, nueve de 10 cultivares de la lista del censo de variedades Hawaianas se originaron de cruzas múltiples (melting pot); solamente una se originó de cruzas biparentales. Debido a la reducción de la industria azucarera de Hawái y al pequeño grupo de trabajo en el programa de mejoramiento genético, la decisión tomada en 1985 fue depender principalmente de los cruzamientos por cruzas múltiples para desarrollar cultivares comerciales. Desde 1985 al 2005, doce clones adicionales provenientes de cruzas previas a 1985, eventualmente fueron denominados ‘cultivares comerciales’ por exceder el 1% del total del área de cultivo de caña. Los doce materiales se originaron de cruzas múltiples (‘melting pot’). Durante el periodo de 50 años en que los dos métodos de cruzamientos fueron usados, se probó que el sistema de cruzas múltiples es más eficiente en el uso de mano de obra comparado con el sistema biparental en el desarrollo de variedades de caña de azúcar en la industria azucarera Hawaiana. Desde 1985 en adelante, los cruzamientos biparentales se usaron mayormente para realizar introgresión de genes específicos, usando materiales foráneos que para el desarrollo de variedades comerciales.
ROOT DENSITY AND DIAMETER OF SUGARCANE CULTIVARS ACROSS THREE LOCATIONS IN CUBA

By

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KEYWORDS: Sugarcane, Root System
Soil Profile Wall, Genotype By Environment.

Abstract

The objective of the present work was to study the density and distribution of sugarcane root systems in a multi-environment trial. Experiments were planted at three locations in the South-Eastern region of Cuba, with 11 sugarcane cultivars. Measurements of root diameter and root density (root numbers/cm³) for fine (FD), thick (ThD) and total (TD) roots were taken using the profile wall method. The root system was evaluated in squares of 20 × 100 cm up to 80 cm depth below the ground surface. Cane yield data (t/ha) and its relations with root system measurements were analysed. Genotype by environment interaction was identified using the AMMI model. Results showed significant (p<0.05) response for root density across genotypes, locations, depths and all interactions. Root depth was the major source of variation. Percentage of total root density was variable from 42.6–55.5% for 0–20 cm depth, dropping to 5.6-11.7% for 60–80 cm depth. Genotypes C86-12, C86-156, B7274 and C88-380 showed similar patterns for t/ha and TD. Moderate but significant (p<0.01) correlations were found between t/ha and FD, ThD and TD.

Introduction

The root system serves important physiological and biochemical functions. A deep-root system should be a desirable characteristic for sugarcane cultivars for the low rainfall regions because this would ensure an ability to endure depletion of soil water (Smith et al., 2005).

However, quantitative information on root distribution in sugarcane is limited. The objective of the present work was to study the density and distribution of sugarcane root systems comparing genotypes across environments in a multi-environment trial.

Materials and methods

The trial was carried out in the South-Eastern region of Cuba at three locations across the sugarcane production zone (Table 1).

Therefore, data from a multi-environment trial were analysed. Eleven sugarcane cultivars: C86-12, B7274, C323-68, C90-317, C86-156, C86-503, C86-531, C88-380 C90-530, C90-647 and C89-250, released in the last 10 years by the Cuban National Institute for Sugarcane Research (INICA) were evaluated.

Experiments at each location were planted in a randomised block design with three replications.

Data were collected from the plant and first ratoon crops. Root evaluation was performed in the first ratoon crop within 12 months. Cane yields (t/ha) for the first ratoon cropping season were recorded.
Table 1—Information of the three test locations of the multi-environment trial.

<table>
<thead>
<tr>
<th>Location</th>
<th>Year planted</th>
<th>Years of harvests</th>
<th>Soil type</th>
<th>Rain per annum (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>County</td>
<td>Name</td>
<td>Code</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Santiago de Cuba</td>
<td>Julio A. Mella</td>
<td>ME</td>
<td>2006</td>
<td>2008–2009</td>
</tr>
<tr>
<td>Granma</td>
<td>Enidio Días</td>
<td>ED</td>
<td>2006</td>
<td>2008–2009</td>
</tr>
</tbody>
</table>

For assessing root diameter (mm) and density (root numbers/cm³), the profile wall method was used (Vasconcelos et al., 2003). Evaluations were made at 0.8 m depth and 1.0 m wide trenches (Figure 1). The profile was divided in squares of 20 x 100 cm up to a soil depth of 80 cm below the ground surface (0–20, 20–40, 40–60 y 60–80 cm). Roots were classified as fine (FD) (0.5–1 mm), thick (ThD) (>1 mm) and total (TD = FD + ThD).

Analysis of variance (ANOVA) was performed to determine the significance of the main effects of genotype, environment and depth. The effect of genotype-environment interaction (GE) was also determined using AMMI models (Gauch et al., 2008), and regression analysis.

**Results and discussion**

Results of analysis of variance (Table 2) showed significant differences for all effects (genotypes, locations and depths) and its interaction. For root density (FD, ThD and TD), depth was the most important source of variation accounting for 42.5, 63.1 and 58%, respectively.

Root diameter also showed significant differences for all effects and every interaction. Root diameter was different from root density for magnitudes of the variance terms. Results showed a lower variance contribution for depth for root diameter.
Table 2—Analysis of variance for root density and diameter.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>FD M.S.</th>
<th>PSS</th>
<th>ThD M.S.</th>
<th>PSS</th>
<th>TD M.S.</th>
<th>PSS</th>
<th>Diameter (mm) M.S.</th>
<th>PSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location (L)</td>
<td>2</td>
<td>0.000072 *</td>
<td>4.0</td>
<td>0.000893 *</td>
<td>5.0</td>
<td>0.003063 *</td>
<td>4.8</td>
<td>1.66 *</td>
<td>6.0</td>
</tr>
<tr>
<td>Rep.(within L)</td>
<td>3</td>
<td>0.000303</td>
<td>0.7</td>
<td>0.00040</td>
<td>0.3</td>
<td>0.00141</td>
<td>0.3</td>
<td>0.03</td>
<td>0.2</td>
</tr>
<tr>
<td>Genotype (G)</td>
<td>10</td>
<td>0.000408 *</td>
<td>10.6</td>
<td>0.000112 *</td>
<td>3.1</td>
<td>0.000770 *</td>
<td>6.1</td>
<td>0.92 *</td>
<td>16.6</td>
</tr>
<tr>
<td>Depth (D)</td>
<td>3</td>
<td>0.005388 *</td>
<td>43.1</td>
<td>0.007574 *</td>
<td>63.1</td>
<td>0.025724 *</td>
<td>60.9</td>
<td>4.17 *</td>
<td>22.7</td>
</tr>
<tr>
<td>GxL</td>
<td>20</td>
<td>0.000111 *</td>
<td>5.8</td>
<td>0.000053 *</td>
<td>2.9</td>
<td>0.000223 *</td>
<td>3.5</td>
<td>0.63 *</td>
<td>22.7</td>
</tr>
<tr>
<td>GxD</td>
<td>30</td>
<td>0.000172 *</td>
<td>13.4</td>
<td>0.000088 *</td>
<td>7.3</td>
<td>0.000415 *</td>
<td>9.8</td>
<td>0.14 *</td>
<td>7.7</td>
</tr>
<tr>
<td>LxD</td>
<td>6</td>
<td>0.000516 *</td>
<td>8.0</td>
<td>0.000468 *</td>
<td>7.8</td>
<td>0.001769 *</td>
<td>8.4</td>
<td>0.32 *</td>
<td>3.4</td>
</tr>
<tr>
<td>GxLxD</td>
<td>60</td>
<td>0.000056 *</td>
<td>8.7</td>
<td>0.000038 *</td>
<td>6.3</td>
<td>0.000135 *</td>
<td>6.4</td>
<td>0.11 *</td>
<td>11.7</td>
</tr>
<tr>
<td>Error</td>
<td>129</td>
<td>0.000021</td>
<td>7.1</td>
<td>0.000016</td>
<td>4.1</td>
<td>0.000048</td>
<td>4.9</td>
<td>0.04</td>
<td>8.9</td>
</tr>
</tbody>
</table>

* indicates significant differences at p<0.05, PSS = Percent of total sum of squares.

As shown in Figure 2, the highest mean total root density (TD) was recorded at Enidio Díaz, and this was significantly different to the other locations. Root density and percent of total roots were different for locations and depth. The Enidio Díaz location had the highest percent total root density in the first 20 cm (55.5%), going down progressively with depth to 5.6% at 80 cm, which was the lowest of the three locations.

![Root density and percent of total roots recorded at each location.](image)

Fig. 2—Root density and percent of total roots recorded at each location.

Leyva et al. (2000), found a negative relation between depth and root numbers. Vasconcelos et al. (2003) reported 72% of total roots in the first 40 cm of soil depth. Physical-chemical properties of the soils at the three locations are shown in Table 3. The Enidio Díaz location has the lowest value for bulk density (BD) and the highest concentration of organic matter (OM). These characteristics seem to improve the development of the sugarcane root system. However, the Mella location, with a sandy soil, has the highest value for BD, the lowest concentration of OM and the poorest root system development.

Table 3—Physical-chemical characteristics of the soils at the three locations.

<table>
<thead>
<tr>
<th>Location</th>
<th>Physicals</th>
<th>Chemical characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BD (g/cm³)</td>
<td>P (%)</td>
</tr>
<tr>
<td>ED</td>
<td>0.95</td>
<td>61.4</td>
</tr>
<tr>
<td>ME</td>
<td>1.35</td>
<td>49.6</td>
</tr>
<tr>
<td>PR</td>
<td>1.12</td>
<td>54.5</td>
</tr>
</tbody>
</table>
**BD—Bulk density  P—Porosity OM—Organic matter**

A regression analysis for cane yield (t/ha) and root density (FD, ThD and TD) (Figure 3) showed a moderated and significant correlation, with the highest $R^2$ value for ThD. These results demonstrate that sugarcane root densities are influenced by the environment and genotype, as their relation with yield is not completely proportional. This suggests genetic differences for root system efficiency.

![Figure 3](image)

**Fig. 3**—Regression analysis for root density (fine (DS), thick (DP) and total (TD)) and cane yield (t/ha). (** indicates significant differences at $p<0.01$ and * $P<=0.05$)

The pattern of genotype by environment interaction for cane yield and total root density was analysed using the AMMI model. For cane yield (Figure 4a), AMMI analysis indicated differences for the three test locations.

At Mella location, C89-250 was the highest yielding genotype. At Enidio Diaz location, the best yielding genotypes were C90-530 and C88-380. At Paquito Rosales, the best performing genotype was C323-68.

The pattern of GE for total root density (Figure 4b) showed differences between the three locations, but genotypes clustered differently compared to cane yield. Genotypes with the best performance across all locations were the same for cane yield and DT: C86-12, C86-156, B7274 and C88-380.

![Figure 4](image)

**Fig. 4**—Biplot of genotype by environment interaction using AMMI model for (a) cane yield (t/ha) and (b) total root density.
Root diameter (Figure 5) showed differences among locations, genotypes and depth. Enidio Diaz location had the lowest mean value for root diameter, significantly different to the other locations. There were also significant differences among genotypes for root diameter. The highest root diameter values were found in the upper soil layer and reduced with soil depth (see colour scale).

Results indicate differential performance of genotypes for root density (FD, ThD and TD) across location and soil depth. The highest root density is found in the upper soil layer (0–20 cm) and directly below the plant. On the other hand, genotypes with high homogeneity for root system distribution in the soil profile could take advantage of soil water. Relationship between root density and agricultural yield is not always direct. It depends on several environmental factors where it is developed. In the future, we will focus on water uptake and shoot eco-physiological traits such as biomass, leaf area, stalk length, etc.

REFERENCES


Fig. 5—Genotypes root diameter and its distribution on soil profile at the three locations.
DENSITÉ ET DIAMÈTRE DES RACINES DES CULTIVARS DE LA CANNE À SUCRE DANS TROIS SITES À CUBA

Par

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MOTS-CLÉS: Canne à Sucre, Système Radiculaire, Technique du Profil Cultural, Génotype par Environnement.

Résumé

Le but de ce travail consistait à étudier la densité et la distribution du système radiculaire de la canne à sucre de 11 cultivars dans des essais multi-locaux établis dans trois sites dans la région du sud-est de Cuba. Une mesure du diamètre et de la densité des racines (nombre de racines par cm³) pour les racines fines (FD), épaisses (ThD) et totales (TD) ont été prélevés par la technique du profil cultural. Le système radiculaire a été évalué en utilisant des grilles de 20 × 100 cm d’une profondeur allant jusqu’à 80 cm. Le rendement de canne (t/ha) et sa relation en fonction des mesures du système radiculaire ont été analysés. Les interactions génotype × environnement ont été identifiées grâce à la modélisation AMMI. Les résultats ont démontré une réponse significative (p<0.05) pour la densité des racines à travers les génotypes, les sites, la profondeur ainsi que pour toutes les interactions. La profondeur des racines a été la source principale de variation. Le pourcentage de la densité totale des racines a varié de 42.6–55.5% pour une profondeur de 0–20 cm, déclinant à 5.6–11.7% pour une profondeur de 60–80 cm. Les génotypes C86-12, C86-156, B7274 et C88-380 ont montré une tendance similaire pour le rendement de canne et la mesure des racines totales. Des corrélations modérées, mais significatives (p<0.01) ont été observées entre le rendement de canne et la mesure des racines totales ainsi que pour les racines épaisses et les racines totales.
ESTUDIO DEL SISTEMA RADICULAR DE LA CAÑA DE AZÚCAR EN TRES LOCALIDADES DE CUBA

Por

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PALABRAS CLAVES: Caña de Azúcar, Raíces, Perfil de Suelo, Interacción Genotipo-Ambiente.

Resumen
El objetivo del presente trabajo fue el estudio de la densidad y distribución del sistema radicular de la caña de azúcar en experimentos multiambientales. Los estudios se plantaron en tres localidades de la región sur oriental de Cuba, con 11 cultivares. Se determinó la densidad (no. raíces/cm³) de las raíces activas finas (DF), gruesas (DG) y total (DT) y su diámetro (mm). Se utilizó el método del perfil de suelo, dividiéndose en áreas de 20 cm × 100 cm, hasta 80 cm de profundidad. Se determinó el rendimiento del cultivo (t caña/ha) y su relación con las variables analizadas, así como, análisis de interacción genotipo-ambiente (IGE) por el modelo AMMI. Los resultados mostraron, que para todas las variables de densidad de raíces, una respuesta diferenciada y significativa (p<0.05) de los genotipos, localidades, y profundidades, así como de sus interacciones. Para el diámetro, la mayor variación fue debida a la profundidad. Los porcentajes de la densidad total de raíces por profundidad y localidad disminuyen desde 42.6–55.5% para la profundidad de 0–20 cm hasta 5.6–11.7% para los 60–80 cm. Los genotipos C86-12, C86-156, B7274 y C88-380 presentaron similar patrón de IGE para las t caña/ha y la DT. Se obtuvieron correlaciones moderadas y significativas respecto a las t caña/ha para la DF, DG y DT.
THE IRANIAN SUGARCANE SELECTION PROGRAM:
AN OVERVIEW OF METHODOLOGIES

By

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KEYWORDS: Selection Program, Genotype-Environment Interaction.

Abstract
The main sources of genetic variation, G × E interaction, response to selection and heritability values were studied in order to establish methodological bases for the selection in initial stages of the Iranian sugarcane breeding program. A representative sample of 10 bi-parental combinations was evaluated in six environments. The component of variance attributable to environment was prevailing and the genotype-environment interaction was significant. Three types of environment were defined and differences between them contributed to selection efficiency. The greatest genetic variability was obtained in the northern region of Khuzestan, and the best results for selection were registered in Imam Khomeini sugar factory’s locality.

Introduction
It is estimated that the consumption of sugar in the Islamic Republic of Iran is around 30 kg per capita with a total demand of 2 million tonnes of refined sugar annually for direct and indirect use. Iran produces 1 300 000 tonnes of sugar, and imports the remainder.

Sugarcane cultivation has increased in the south of Iran and in Khuzestan province, and Iran aims to be self-sufficient in sugar and develop various by-products. In fact, the Sugarcane and By-Products Development Corporation has been created to produce sugar, animal food, paper, particle boards, pulp paper and other by-products.

This has motivated special interest in the adoption of modern technologies and improved cultivars. Therefore, the National Breeding Program is working under special climatic conditions in Khuzestan to grow sugarcane, with different environmental stress conditions (drought, salinity and freeze). The main commercial varieties are CP48-103, CP57-614, CP69-1062 and NCo310.

The particular growing conditions enabled a study of genotype-environment interaction, its sources of variation and genetic parameters that allow breeders to establish methodologies and bases for the Breeding and Selection of sugarcane in Iran and here we present a summary of the results.

Materials and methods
The experiments were planted between September 2003 and March 2007, in three locations of the Sugarcane Research Center, belonging to Sugarcane and By-Products Development Corporation in Khuzestan province.

Progenies of 10 bi-parental combinations of representative commercial varieties of different geographical origin were evaluated in a randomised block design. Each combination had a
population of 60 seedlings and the evaluations were carried out in plant cane and first ratoon at 10 and 12 months respectively. Data were taken for plant height, stem diameter, number of stems and brix, following procedures described by Jorge et al. (2002) and Hamdi et al. (2003).

Analysis of variance of double classification (clones × locality) was performed to identify the sources of genotype × environment interaction (G × E) using a factorial model (Cochran and Cox, 1965).

The model of simple classification of randomised effect balanced proposed by Kempthorne (1952) was used to estimate the statistical genetic parameters for each of the localities. Heritability estimates in narrow sense (h²e) were calculated from the components of variance (Hogarth, 1968; Milligan et al., 1990).

The approximate standard error was obtained according to Anderson and Bancroft (1952) and Becker (1984) and the genetic coefficient of variation (CGV) according to Falconer (1970). To compare the selection efficiency between localities and characters, the response to selection (R) was utilised and a selection index (ΔG) of 40% of the population selected was utilised (Falconer, 1970; Cesnik and Vencovsky, 1974).

**Results and discussion**

The analysis of variance shows significant differences (p = 0.05) in the G × E interaction in most of the evaluated characters, but not for brix in plant cane and number of stems in first ratoon. This can affect selection efficiency, reaffirming the importance of replication in time and space (Table 1).

Drought stress under these cultivation conditions, with water deficiency combined with high temperatures, might be the reason for the high values presented here. The heritability values estimated in first ratoon confirm the previous results for stem height and field brix as major trends. The genetic coefficient of variation (CVG) had very similar behaviour.

Localities presented the most important source of variation in plant cane and first ratoon for stem height. On the other hand, stem diameter was the character with no location effects. For the remaining characters, experimental error proved to be the main source of variation.

The heritability values and their consistency calculated for each locality were very low for the different environments for cane yield, and the rest of the components of cane yield (Table 2). These results do not agree with Garcia (2004) for conditions of drought stress in Cuba, who found genetic variability for diameter.

Other statistical genetic parameters evaluated were genetic variance (σ²g), genetic coefficient of variation (GCV), response to selection and selection gain, but heritability values might be the best criteria for selection for cane yield in seedling stage in Iran, using stem height and stem diameter. Sugar content might be useful for selection in first ratoon.

Selection efficiency is evaluated using the balance between genetic components and phenotypic expression. The best results of selection were expected at Imam Khomeini in plant cane for three of the four characters (stem diameter, stem height and number of stems).

In terms of the G × E interactions and the main statistical genetic parameters, three types of environments in Khuzestan were confirmed to contribute to selection efficiency, relating to the types of soil and environmental conditions. Environments in the northern Province show great variability where selection in seedling stage will provide better results. A climatic zones classification confirmed differences between Imam Khomeini and Mian Abb localities. The first one shows better efficiency. The southern environment (Amir Kabir) did not show major differences in genetic statistical parameters.

These results show the importance of adopting strategies for selection in the seedling stage, but not assign major importance to evaluation in ratoon, applying low to moderate selection intensity to allow selection of a high proportion of individuals from the population.
Table 1—Variance components and genetic parameters.

<table>
<thead>
<tr>
<th>Variance components</th>
<th>Plant cane</th>
<th></th>
<th></th>
<th>First ratoon</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\sigma^2)</td>
<td>SE</td>
<td>PTV</td>
<td>(\sigma^2)</td>
<td>SE</td>
<td>PTV</td>
</tr>
<tr>
<td>Stem height</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\sigma^2g)</td>
<td>73.19 ± 49.45</td>
<td>2.2</td>
<td>230.87 ± 113.52</td>
<td>** 6.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\sigma^2l)</td>
<td>4923.08 ± 3489.96</td>
<td>75.2</td>
<td>2873.78 ± 2039.57</td>
<td>50.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\sigma^2gxl)</td>
<td>96.57 ± 37.39 **</td>
<td>1.5</td>
<td>79.54 ± 33.55 **</td>
<td>1.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\sigma^2e)</td>
<td>936.61 ± 23.45 **</td>
<td>21.0</td>
<td>1592.85 ± 37.84 **</td>
<td>41.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EV</td>
<td>5859.70</td>
<td>96.23</td>
<td>4466.63</td>
<td>92.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>160.03</td>
<td></td>
<td>185.77</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(h^2)</td>
<td>0.33 ± 0.22</td>
<td>0.44 ± 0.21 **</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GCV (%)</td>
<td>5.35</td>
<td></td>
<td>8.18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stem diameter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\sigma^2g)</td>
<td>0.01 ± 0.05</td>
<td>2.9</td>
<td>0.03 ± 0.07</td>
<td>8.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\sigma^2l)</td>
<td>0.00 ± 0.02</td>
<td>0.0</td>
<td>0.02 ± 0.04</td>
<td>2.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\sigma^2gxl)</td>
<td>0.01 ± 0.01</td>
<td>2.1</td>
<td>0.38 ± 0.13 **</td>
<td>14.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\sigma^2e)</td>
<td>0.57 ± 0.01 **</td>
<td>95.0</td>
<td>1.22 ± 0.03 **</td>
<td>74.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EV</td>
<td>0.57</td>
<td>95.0</td>
<td>1.25</td>
<td>76.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>2.20</td>
<td></td>
<td>2.39</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(h^2)</td>
<td>0.02 ± 0.08</td>
<td>0.08 ± 0.21</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GCV (%)</td>
<td>5.03</td>
<td></td>
<td>6.73</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of stems</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\sigma^2g)</td>
<td>1.45 ± 0.83</td>
<td>3.1</td>
<td>4.53 ± 2.23 **</td>
<td>3.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\sigma^2l)</td>
<td>19.61 ± 13.97</td>
<td>24.4</td>
<td>17.99 ± 12.88</td>
<td>9.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\sigma^2gxl)</td>
<td>0.58 ± 0.41</td>
<td>1.3</td>
<td>0.27 ± 0.68</td>
<td>1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\sigma^2e)</td>
<td>39.01 ± 0.98 **</td>
<td>71.2</td>
<td>112.56 ± 2.68 **</td>
<td>85.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EV</td>
<td>58.63</td>
<td>95.6</td>
<td>130.55</td>
<td>95.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>15.33</td>
<td></td>
<td>17.90</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(h^2)</td>
<td>0.39 ± 0.22</td>
<td>0.43 ± 0.21 **</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GCV (%)</td>
<td>7.85</td>
<td></td>
<td>11.89</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field brix</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\sigma^2g)</td>
<td>1.88 ± 1.08</td>
<td>2.8</td>
<td>1.85 ± 0.83 **</td>
<td>12.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\sigma^2l)</td>
<td>18.40 ± 13.13</td>
<td>16.0</td>
<td>5.07 ± 3.61</td>
<td>23.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\sigma^2gxl)</td>
<td>0.53 ± 0.53</td>
<td>1.2</td>
<td>0.12 ± 0.09</td>
<td>1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\sigma^2e)</td>
<td>62.80 ± 1.57 **</td>
<td>80.0</td>
<td>9.10 ± 0.22 **</td>
<td>62.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EV</td>
<td>81.20</td>
<td>96.0</td>
<td>14.17</td>
<td>86.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>14.94</td>
<td>1.2</td>
<td>15.91</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(h^2)</td>
<td>0.38 ± 0.21</td>
<td>0.47 ± 0.20 **</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GCV (%)</td>
<td>9.17</td>
<td></td>
<td>8.55</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(\sigma^2\). Component of variance g: genotype l: locality gxl: genotype x locality interaction e: experimental error EV: Environments variance SE: Standard error PTV: Percent of total variance **: Precise Estimate (≤2\(\sigma^2\)) \(h^2\): heritability GCV: Genetic Coefficient of Variation
### Table 2—Variance components and genetic parameter for locality.

<table>
<thead>
<tr>
<th>Locality</th>
<th>Stem height</th>
<th>Stem diameter</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\sigma^2_G$</td>
<td>$\sigma^2_E$</td>
<td></td>
</tr>
<tr>
<td>Amir Kabir</td>
<td>337.27 ± 14.95 (28.8)</td>
<td>0.02 ± 0.00 (12.7)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>835.28 ± 34.33 (71.2)</td>
<td>0.14 ± 0.01 (87.3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10.14</td>
<td>6.37</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$h_e^2$ 0.58 ± 0.03</td>
<td>0.25 ± 0.01</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R 19.37</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Delta G$ 0.57</td>
<td>0.24</td>
<td></td>
</tr>
<tr>
<td>Imam Khomeini</td>
<td>445.96 ± 19.70 (30.7)</td>
<td>0.02 ± 0.00 (11.3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1007.19 ± 41.40 (69.3)</td>
<td>0.19 ± 0.01 (88.7)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15.70</td>
<td>6.92</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$h_e^2$ 0.61 ± 0.03</td>
<td>0.23 ± 0.01</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R 45.85</td>
<td>0.09</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Delta G$ 1.22</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>Mian Abb</td>
<td>147.95 ± 8.39 (4.8)</td>
<td>1.16 ± 0.05 (25.8)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2936.08 ± 120.67 (95.2)</td>
<td>3.34 ± 0.14 (74.2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.03</td>
<td>40.22</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$h_e^2$ 0.10 ± 0.01</td>
<td>0.52 ± 0.02</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R 1.98</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Delta G$ 0.04</td>
<td>0.42</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of items</th>
<th>Refractometric brix</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma^2_G$</td>
<td>5.47 ± 0.29 (5.9)</td>
</tr>
<tr>
<td>$\sigma^2_E$</td>
<td>86.91 ± 3.57 (94.1)</td>
</tr>
<tr>
<td>CVG</td>
<td>12.15</td>
</tr>
<tr>
<td>$h_e^2$</td>
<td>0.12 ± 0.01</td>
</tr>
<tr>
<td>R</td>
<td>0.47</td>
</tr>
<tr>
<td>$\Delta G$</td>
<td>0.05</td>
</tr>
<tr>
<td>Amir Kabir</td>
<td></td>
</tr>
</tbody>
</table>

| Imam Khomeini   |                       |                       |
| $\sigma^2_G$    | 4.42 ± 0.23 (7.3)     | 1.81 ± 0.08 (19.3)   |
| $\sigma^2_E$    | 55.90 ± 2.31 (92.7)   | 7.55 ± 0.31 (80.7)   |
| CVG             | 16.05                | 7.53                  |
| $h_e^2$         | 0.15 ± 0.01          | 0.39 ± 0.02           |
| R               | 2.46                 | 0.67                  |
| $\Delta G$      | 0.32                 | 0.22                  |

| Mian Abb        |                       |                       |
| $\sigma^2_G$    | 4.60 ± 0.34 (2.3)     | 1.82 ± 0.09 (13.6)   |
| $\sigma^2_E$    | 194.47 ± 8.01 (97.7)  | 11.57 ± 0.48 (86.4)  |
| CVG             | 10.06                | 10.05                 |
| $h_e^2$         | 0.05 ± 0.00          | 0.27 ± 0.01           |
| R               | 0.51                 | 1.37                  |
| $\Delta G$      | 0.04                 | 0.38                  |

$\sigma^2_G$, Genetic variance $\sigma^2_E$, Error variance CVG, Genetic coefficient of variation $h_e^2$. Heritability R, Response to the selection $\Delta G$. Profit for selection.
Conclusion

1. A suitable strategy for the selection will be to conduct it in ratoon with low to moderate intensity and using the length of stalk and refractometric brix as the principal criteria.

2. The environmental effect proved to be the most important source of variation (76-96% of the total phenotypic variation) with a reduction in ratoon.

3. Three types of environments were identified, according to the soil classification, and these contribute to the differences in the efficiency of the selection. Imam Khomeini is the most effective locality for selection.

4. The need to enlarge the genetic base used was ratified for breeding purposes.

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LE PROGRAMME DE SÉLECTION DE CANNE À SUCRE IRANIEN: 
UNE VUE DE L’ENSEMBLE DES MÉTHODOLOGIES

Par
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MOTS-CLÉS: Programme de Sélection, 
Interaction Génotype-Environnement.

Résumé
LES SOURCES principales de la variation génétique, l’interaction G × E, la réponse à la sélection et 
les valeurs d’héritabilité ont été étudiées afin d’établir la méthodologie de base pour la sélection au 
stade préliminaire du programme d’amélioration génétique de la canne à sucre iranien. Un 
échantillon représentatif de 10 combinaisons bi-parentales ont été évaluées dans six 
environnements. La composante de variance imputable à l’environnement était prévalente et 
l’interaction génotype-environnement était significative. Trois types d’environnements ont été 
définis et les différences parmi eux relèvent de l’efficacité de la sélection. La plus importante 
variabilité génétique a été observée dans les régions septentrionales du Khuzestan, et les meilleurs 
résultats pour la sélection ont été enregistrés dans la localité de la sucrerie de l’Imam Khomeini.

EL PROGRAMA DE SELECCIÓN IRANÍ DE CAÑA DE AZÚCAR: UNA VISIÓN 
GENERAL DE LAS METODOLOGÍAS

Por
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PALABRAS CLAVES: Programa de Selección de Caña, 
Interacción Genotipo-Ambiente.

Resumen
LAS PRINCIPALES fuentes de variación genética, la interacción G × A, la respuesta a selección y los 
valores de heredabilidad se estudiaron con miras a establecer las bases metodológicas para 
seleccionar en estados iniciales de selección dentro del Programa de Selección de Caña de Azúcar 
de Irán. Una muestra representativa de 10 combinaciones biparentales fue evaluada en seis 
enambientes diferentes. Los componentes de variación atribuidos al ambiente fueron los más notorios 
y la interacción G × A fue significativa. Tres tipos de ambientes fueron definidos y las diferencias 
entre ellos contribuyeron a la eficiencia de la selección. La mayor variabilidad genética se obtuvo 
en la región norte de Khuzestan y los mejores resultados de selección se registrados en la localidad 
de la empresa Imam Khomeini.
EVALUATION OF BROWN RUST RESISTANCE
(Puccinia melanocephala) IN SUGARCANE PROGENIES

By

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L.R. PINTO1, S. CRESTE1, M.B.B. SOARES3

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KEYWORDS: Sugarcane, Disease Resistance, Brown Rust.

Abstract

The present work is aimed at evaluating rust (Puccinia melanocephala H. & P. Syd) resistance in sugarcane progeny as well as identifying parents able to produce progeny with a high percentage of resistant individuals that can be used as a source of resistance in a breeding program. Ten families derived from biparental crosses were evaluated for rust resistance in a randomised block design with four replicates with 50 seedlings per replication. Rust resistance was evaluated by visually rating on a scale of 1–9 based on infection on all leaves. The lowest means and variances were observed for families 9 (1.82 and 3.05) and 10 (1.06 and 0.5) in which the variety IACSP94-2094 was used as a parent. Individuals in families 8, 9 and 10 showed a 3:1 resistant:susceptible ratio, suggesting the presence of one major gene with a dominant effect. The results identify the varieties IACSP94-2094, IACSP91-2195 and SP83-2847 as sources of rust resistance.

Introduction

Sugarcane brown rust caused by the fungus Puccinia melanocephala H. & P. Syd is considered one of the main diseases of sugarcane with important economic losses in susceptible varieties (Matsuoka et al., 1999).

Rust resistance has been considered a quantitatively inherited trait, with moderate to high heritability. In the past, sugarcane rust evaluation has been based on a subjective rating scale for disease severity (Hogarth, 1987, Asnaghi et al., 2001).

Although sugarcane resistance is considered quantitatively inherited, a 3:1 segregation ratio indicative of a major gene with dominance effect was observed in progeny derived from the self of the variety R570 (Daugrois et al., 1996).

Since the use of sugarcane varieties resistant to rust is the best method for controlling the disease, the present work aimed to evaluate brown rust resistance segregation in 10 sugarcane families and also to identify parents that are able to generate a high proportion of individuals resistant to brown rust for use in a breeding program.

Material and methods

Brown rust resistance was evaluated in 10 families derived from bi-parental crosses between parents with different rust ratings (Table 1).

The experiment was planted in October 2007 at the Sugarcane Center from the Instituto Agronômico Campinas, Ribeirão Preto, SP, Brazil. Each family was composed of 200 individuals derived from hybridisations made in 2007. The experimental design was randomised complete
block with four replicates containing 50 individuals per family. Plots were composed of 5 rows, six metres long, with 1.5 m spacing between rows and 0.6 m between plants. Each replication was planted in a homogeneous area of the field.

Plants were rated in the field for rust, using a scale which ranged from 1 (resistant) to 9 (susceptible) (Amorim et al., 1987).

Scores between one and three were considered resistant, four to six intermediate, and seven to nine susceptible. The SASR (1999) package was used in the analysis of variance, and means and family variance estimations.

The Tukey test was applied to verify statistically significant differences among the family means. To test the hypothesis of a 3:1 segregation ratio (resistant/susceptible), the individuals of each family were separated in two classes: resistant (score = 1.0) and susceptible (score ≥ 2) applying the Chi-square test with 1 degree of freedom.

**Results and discussion**

The lowest means and variances were observed for the families 9 (1.82 and 3.05) and 10 (1.06 and 0.5) in which the variety IACSP94-2094 was used as parent (Table 1).

The low mean and variance values of these two families indicate that most of the individuals are resistant with little phenotypic variability for rust resistance, particularly for individuals from Family 10.

These two families had means that differed significantly from those of families 1, 2, 3 and 4 (Table 1).

**TABLE 1**—Mean and variance of each family for rust resistance.

<table>
<thead>
<tr>
<th>Family</th>
<th>Mean</th>
<th>Variance (s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - IACSP95-3028 X IACSP95-2078</td>
<td>3.83 ABCDEF</td>
<td>8.79</td>
</tr>
<tr>
<td>2 - IACSP95-3028 X SP79-1011</td>
<td>4.34 ABC</td>
<td>8.73</td>
</tr>
<tr>
<td>3 - IACSP95-2078 X IACSP96-2019</td>
<td>4.35 AB</td>
<td>8.65</td>
</tr>
<tr>
<td>4 - IACSP95-2078 X SP83-2847</td>
<td>2.80 BCDEFGHI</td>
<td>7.56</td>
</tr>
<tr>
<td>5 - SP89-1115 X IACSP97-6682</td>
<td>3.96 ABCDE</td>
<td>7.37</td>
</tr>
<tr>
<td>6 - IACSP96-2042 X SP80-185</td>
<td>1.97 EFGHI</td>
<td>4.53</td>
</tr>
<tr>
<td>7 - SP83-2847 X IACSP95-5011</td>
<td>1.98 EFGHI</td>
<td>3.98</td>
</tr>
<tr>
<td>8 - IAC91-2195 X SP80-3280</td>
<td>2.17 DEFGHI</td>
<td>3.38</td>
</tr>
<tr>
<td>9 - IACSP95-2078 X IACSP94-2094</td>
<td>1.82 FGHI</td>
<td>3.05</td>
</tr>
<tr>
<td>10 - IACSP94-2094 X SP83-2847</td>
<td>1.06 I</td>
<td>0.5</td>
</tr>
<tr>
<td>Mean</td>
<td>2.28</td>
<td>5.65</td>
</tr>
</tbody>
</table>

Means with the same letters did not differ significantly at the 5% level (Tukey).

Of the 10 families evaluated, families seven, eight, and nine did not deviate significantly from the 3:1 ratio ($\alpha=0.05$), suggesting the presence of a major gene for resistance in one of the parents (Daugrois et al., 1996).

Family ten did not segregate for susceptibility (1:0 ratio), i.e. all the individuals were resistant (Table 2). This suggests that there is probably a major dominant gene for rust resistance in both parents. According to Hogarth et al. (1993), families derived from crosses between resistant parents are likely to yield resistant progeny.

The deviation in relation to the 2:1 ratio was not significant at (p<0.05) for families 5 and 6. The rest of the families deviated from the expected 3:1 ratio when a single major gene is involved. Families number 1 and 2 showed one resistant individual to each two susceptible ones (1:2) which matches the expected ratio for the presence of minor genes without dominance. Family number 3 had a high severity of rust, with a ratio of one resistant for every three susceptible (Table 2).
TABLE 2—Chi-square test for rust resistance for segregation hypotheses 3:1 ($X^2$, 3:1) and other segregation ratios ($X^2$, suggested by data).

<table>
<thead>
<tr>
<th>Nº. Family</th>
<th>Cross</th>
<th>Parent score</th>
<th>Observed (R:S)</th>
<th>$X^2$ (3:1)</th>
<th>Suggested H0 (R:S)</th>
<th>$X^2$ Suggested</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>IACSP95-3028 × IACSP95-2078</td>
<td>2:4</td>
<td>60:115</td>
<td>154.71</td>
<td>1:2</td>
<td>0.07</td>
</tr>
<tr>
<td>2</td>
<td>IACSP95-3028 × SP79-1011</td>
<td>2:8</td>
<td>72:109</td>
<td>119.75</td>
<td>1:2</td>
<td>3.37</td>
</tr>
<tr>
<td>3</td>
<td>IACSP95-2078 × IACSP96-2019</td>
<td>4:4</td>
<td>57:136</td>
<td>212.78</td>
<td>1:3</td>
<td>2.11</td>
</tr>
<tr>
<td>4</td>
<td>IACSP95-2078 × SP83-2847</td>
<td>4:1</td>
<td>89:106</td>
<td>89.64</td>
<td>1:1</td>
<td>1.4</td>
</tr>
<tr>
<td>5</td>
<td>SP89-1115 × IACSP97-6682</td>
<td>4:7</td>
<td>128:58</td>
<td>3.79</td>
<td>2:1</td>
<td>0.38</td>
</tr>
<tr>
<td>6</td>
<td>IACSP96-2042 × SP80-185</td>
<td>6:1</td>
<td>99:67</td>
<td>20.89</td>
<td>2:1</td>
<td>3.69</td>
</tr>
<tr>
<td>7</td>
<td>SP83-2847 × IACSP95-5011</td>
<td>1:3</td>
<td>139:39</td>
<td>0.67</td>
<td>3:1</td>
<td>0.67</td>
</tr>
<tr>
<td>8</td>
<td>IAC91-2195 × SP80-3280</td>
<td>1:2</td>
<td>153:39</td>
<td>2.25</td>
<td>3:1</td>
<td>2.25</td>
</tr>
<tr>
<td>9</td>
<td>IACSP95-2078 × IACSP94-2094</td>
<td>4:1</td>
<td>142:45</td>
<td>0.09</td>
<td>3:1</td>
<td>0.09</td>
</tr>
<tr>
<td>10</td>
<td>IACSP94-2094 × SP83-2847</td>
<td>1:1</td>
<td>184:4</td>
<td>49.38</td>
<td>1:0</td>
<td>0.00</td>
</tr>
</tbody>
</table>

p-value < 0.05, $X^2$>=3.84.

Ramdoyal et al. (2000) conducted a study using parents with differential resistance to rust and reported that families derived from crosses between two resistant parents generated mostly resistant progeny while crosses between susceptible and highly susceptible parents produced families with a majority of susceptible individuals.

These results agree with the field observations from this study in which the variety IACSP95-2078 generated progeny with severe disease symptoms with the exception of the cross using this parent with IACSP94-2094.

The results from the current study suggest varieties IAC91-2195, SP83-2847 and, especially IACSP94-2094, are good sources of rust resistance.

REFERENCES


EVALUATION DES PROGÉNITURES DE LA CANNE À SUCRE À LA ROUILLE BRUNE (*PUCCINIA MELANOCEPHALA*)

Par

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*MOTClÉS: Canne à Sucre, Résistance aux Maladies, Rouille Brune.

Résumé

LA PRÉSENTE étude vise à évaluer la résistance à la rouille brune (*Puccinia melanocephala* H. & P. Syd) dans les progénitures de la canne à sucre, aussi bien que d’identifier les parents capables d’engendrer des progénitures avec un pourcentage élevé des individus résistants. Ceux-ci peuvent ensuite être utilisés dans un programme d’amélioration variétale. Dix familles, dérivées d’un croisement bi-parental étaient évaluées pour leur résistance à la rouille en bloc randomisé comprenant quatre répétitions avec 50 plantules par répétition. La résistance a été évaluée visuellement sur une échelle de 1-9 basé sur l’infection de toutes les feuilles. Les moyennes et les variances les plus bas ont été observées pour les familles 9 (1.82 et 3.05) et 10 (1.06 et 0.5) au sein de lesquels figurait la variété IACSP94-2094 utilisée comme parent. Les individus dans les familles 8, 9 et 10 étaient repartis dans un ratio 3:1 de résistants par rapport aux sensibles, suggérant la présence d’un gène majeur avec effet dominant. Les résultats ont permis l’identification des variétés IACSP94-2094, IACSP91-2195 et SP83-2847 comme source de résistance à la rouille.
EVALUACIÓN DE LA RESISTENCIA ALA ROYA ANARANJADA
(Puccinia melanocephala) EN PROGENIES DE CAÑA DE AZÚCAR

Por

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PALABRAS CLAVES: Caña de Azúcar,
Resistencia a Enfermedades, Roya Común.

Resumen

EL PRESENTE trabajo tiene como objetivo principal evaluar la resistencia a roya común (Puccinia melanocephala H. & P. Syd), en progenies de caña de azúcar, así como identificar parentales que muestren una producción de progenies con alto porcentaje de individuos resistentes para que puedan ser usados como fuente de resistencia para los programas de mejoramiento genético. Diez familias derivadas de un cruce biparental fueron evaluados para la resistencia a roya anaranjada en un ensayo de bloques al azar con 4 repeticiones de 50 plantas por replicación. La resistencia se evaluó usando una escala de 1 – 9, basado en la infección de las hojas. Las medias más bajas y las varianzas fueron observadas por las familias 9 (1.82 y 3.05) y 10 (1.06 y 0.5) en las cuales la variedad IACSP94-2094 fue usada como parental. Varios individuos en las familias 8, 9 y 10 presentaron una relación 3:1 de resistencia: susceptibilidad, sugiriendo la presencia de un gen mayor con efectos dominantes. Los resultados presentados, sugieren que las variedades IACSP94-2094, IACSP91-2195 and SP83-2847 pueden ser una fuente de resistencia a esta enfermedad.
REPEATABILITY ESTIMATES IN EARLY MATURING SUGARCANE GENOTYPES

By

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KEYWORDS: Saccharum spp., Repeatability, Maturation, Breeding.

Abstract

The Republic of Brazil (code sign RB) varieties are covering up to 58% of the Brazilian sugarcane cultivated area. The objective of this work was to evaluate the repeatability estimates in twenty two early maturing sugarcane genotypes and to recommend a minimum measurement number for real prediction of performance at the final experimental stage of selection. All these genotypes belong to the Sugarcane Breeding Program of the Federal University of São Carlos/RIDESA and are denominated RB (Republic of Brazil). Seven field trials were established in randomised complete blocks with four replicates. The assayed characters were cane yield, sucrose content, sucrose yield and fibre content. Three statistical methods were applied to obtain the repeatability estimates: analysis of variance (ANOVA), principal components and structural analysis. It was observed that the three methods presented similar performance for all the characters. The lower average value of the repeatability estimate \( r = 0.40 \) for sucrose content, with a confidence around 70%, indicated a major environmental effect on this parameter in the early maturing stage. Fibre content and cane yield showed mean repeatability estimates just over 0.60, with a confidence around 80%. Therefore, this behaviour of early maturing sugarcane genotypes suggests that at least four ratoon crops should be accomplished at this stage to obtain approximate real value predictability of 80% considering all characters.

Introduction

In Brazil, the average sugarcane productivity has increased in commercial fields by about 60% over the last thirty years. This significant increment was possible due to the efficiency of the Brazilian sugarcane breeding programs in the development and release of improved genotypes.

Currently, many sugarcane varieties from different research institutes are used by sugar and alcohol industries, and RB (Republic of Brazil) varieties are covering up to 58% of the Brazilian sugarcane cultivated area.

Maturation is an important aspect in the sugarcane genetic improvement. The selection process of genotypes to release a variety takes many years and locations of experimentation (Mamet and Domainingue, 1999). Varieties must be evaluated in several periods corresponding to the beginning, middle and end of sucrose extraction. Early, intermediate and final maturing sugarcane varieties are the fundamental raw material for sugar and alcohol production in Brazil (Matsuoka, 2001).
Repeatability is an indispensable parameter in the genetic improvement of perennial crops. Repeatability is measured by the correlation for the various measurements of characters between crops and environments (Falconer and Mackay, 1996). Therefore, repeatability enables breeders to consider the characters that are repeated more than once during cultivation and to estimate a minimum measurement number for real prediction of individuals (Vencovský, 1973).

The objective of this work was to evaluate repeatability estimates in twenty two early maturing sugarcane genotypes and to recommend a minimum measurement number for real prediction of performance at the final experimental stage of selection.

**Materials and methods**

Seven field trials were established at different locations (environments) of São Paulo State/Brazil and in randomised complete blocks with four replicates (single row 8 m plots) to evaluate twenty two early maturing RB (Republic of Brazil) sugarcane genotypes. These genotypes belong to the final experimental stage of the Sugarcane Breeding Program of Federal University of São Carlos/RIDESAU.

The assayed characters over three ratoon crops were cane yield, sucrose content, sucrose yield and fibre content. Three statistical methods were applied to obtain the repeatability (r) estimates: analysis of variance (Cruz et al., 2004), which also estimated the genetic variability and the environment coefficient of variation (CV%) for each character; principal components (Abeywardena, 1972), based on the matrix of correlations of the ratoon-crops measurements; and structural analysis (Mansour et al., 1981), considering the arithmetic mean of the phenotypic correlations between genotypes in the ratoon-crops measurements.

The coefficient of determination ($R^2$) was calculated from repeatability estimates obtained of each applied method and location, and the minimum measurement number was obtained based on the expression related by Lush (1937).

**Results and discussion**

The coefficient of variation (CV%) for the characters cane yield and sucrose yield were similar and less than 10% (Table 1), indicating an acceptable precision of the experiments. For the characters sucrose content and fibre content, the CV remained around 4%, an expected value for the characters that are determined under laboratory conditions.

<table>
<thead>
<tr>
<th>Character</th>
<th>CV %</th>
<th>ANOVA</th>
<th>PC</th>
<th>SA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>r</td>
<td>R²</td>
<td>r</td>
</tr>
<tr>
<td>Cane yield</td>
<td>7.97</td>
<td>0.60</td>
<td>0.81</td>
<td>0.62</td>
</tr>
<tr>
<td>Sucrose content</td>
<td>3.77</td>
<td>0.40</td>
<td>0.64</td>
<td>0.43</td>
</tr>
<tr>
<td>Sucrose yield</td>
<td>9.07</td>
<td>0.50</td>
<td>0.73</td>
<td>0.52</td>
</tr>
<tr>
<td>Fibre content</td>
<td>4.03</td>
<td>0.65</td>
<td>0.83</td>
<td>0.67</td>
</tr>
</tbody>
</table>

The results of the three statistical methods for estimating repeatability are presented in Table 1. It was observed that the three methods gave similar results for all the characters. Results of this magnitude were also obtained by Ferreira et al. (2005), who estimated the coefficient of repeatability through the same statistical methods in several sugarcane genotypes over sixteen locations in Brazil.

The analysis of variance (ANOVA) method has been the most used to determine the coefficient of repeatability estimate. However, according to Abeywardena (1972), the principal components method is the most efficient when the characters have considerable genetic variation.
The average estimates of the repeatability (r) and the coefficient of determination ($R^2$) are presented in Table 1. The lower average values of the repeatability estimate considering the three statistical methods ($r = 0.40$; $r = 0.43$; $r = 0.42$) for sucrose content, with a confidence of about 70%, indicated a major environmental effect on this parameter in the early maturing stage. One of the possible reasons for this occurrence would be the various stresses that early maturing varieties are subjected to over the years of cultivation, due to the limited environmental conditions for vegetative growth. Fibre content and cane yield showed mean repeatability estimates just over 0.60, with a confidence of about 80%.

The minimum measurement number for real prediction of individuals is given in Table 2. Three evaluations over the years would be sufficient for the characters cane yield and fibre content, considering a confidence of approximately 80%. In contrast, sucrose content and sucrose yield would have similar confidence after six and five measurements (principal components), respectively. Santos et al. (2004) consider more than five measurements to be unviable economically. Therefore, this behaviour of early maturing sugarcane genotypes suggests that at least four ratoon crops should be accomplished at this stage to obtain approximate real value predictability of 80% considering all characters.

### Table 2—Minimum Measurement Number obtained by the methods of analysis of variance (ANOVA), principal components (PC) and structural analysis (SA) for all characters – average data from seven locations.

<table>
<thead>
<tr>
<th>Character</th>
<th>ANOVA R^2</th>
<th>PC R^2</th>
<th>SA R^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane yield</td>
<td>0.80</td>
<td>0.85</td>
<td>0.90</td>
</tr>
<tr>
<td>Sucrose content</td>
<td>8.07</td>
<td>11.43</td>
<td>18.16</td>
</tr>
<tr>
<td>Sucrose yield</td>
<td>5.28</td>
<td>7.48</td>
<td>11.88</td>
</tr>
<tr>
<td>Fibre content</td>
<td>2.54</td>
<td>3.60</td>
<td>5.71</td>
</tr>
</tbody>
</table>

Conclusions
The three methods, analysis of variance (ANOVA), principal components and structural analysis, presented similar repeatability estimates. The results obtained for early maturing sugarcane genotypes suggest that at least four ratoon crops should be accomplished to obtain approximate real value predictability of 80% considering all characters.

Acknowledgments
We wish to acknowledge the enormous dedication of everybody in our team and Professor Marineide Mendonça Aguillera for technical suggestions concerning English.

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ESTIMATIONS DE RÉPÉTABILITÉ POUR LA SÉLECTION DES GÉNOTYPES HÂTIFS DE CANNE À SUCRE

Par

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KEYWORDS: Saccharum spp., Répétabilité, Maturation, Amélioration Génétique.

Résumé
Les variétés de canne à sucre de la République du Brésil (code RB) sont cultivées jusqu’à 58% de la surface sous canne au Brésil. L’objectif de cette étude était d’évaluer les estimations de répétabilité pour 22 variétés hâtives de canne à sucre et de recommander un nombre minimum de variétés pour la prédiction réelle de la performance au stade finale de sélection. Toutes les gènotypes appartiennent au Sugarcane Breeding Program de l’Université Fédérale de São Carlos/RIDESA et portent la domination RB (République du Brésil). Sept essais, disposés en blocks complets randomisés et comprenant quatre répétitions, ont été plantés. Les caractères évalués étaient le rendement en canne et en sucre ainsi que la teneur en saccharose et en fibre. Trois méthodes statistiques ont été utilisées pour obtenir les estimations de répétabilité: l’analyse de variance (ANOVA), les analyses en composantes principales et l’analyse structurale. Il a été observé que les trois méthodes présentaient la même fiabilité pour tous les caractères. La valeur moyenne relativement faible de l’estimation de répétabilité (r = 0.40) pour la teneur en saccharose, avec une confiance autour de 70%, a démontré un effet majeur de l’environnement sur ce paramètre au stade précoce de la maturation. La teneur en fibre et le rendement en canne ont montré une moyenne de l’estimation de répétabilité tout juste au-dessus de 0.60, avec une confiance autour de 80%. De ce fait, le comportement des gènotypes hâtifs tend à démontrer qu’au moins quatre repousses devront être évaluées à ce stade pour obtenir la valeur approximative réelle de prédiction de 80% en prenant en considération tous ces caractères.
ESTIMADOS DE REPETIBILIDAD EN GENOTIPOS DE CAÑA DE AZÚCAR DE MADUREZ TEMPRANA

Por

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PALABRAS CLAVES: \textit{Saccharum spp.}, Repetitividad, Maduración Caña, Mejoramiento Genético.

Resumen

LAS VARIEDADES República de Brasil (códigos RB) actualmente cubren hasta el 58\% del área cultivada con caña de azúcar. El objetivo de éste trabajo fue evaluar los estimados de repetitividad de 20 genotipos de maduración temprana y recomendar un número mínimo de medidas para predicciones reales de individuos en los últimos estados de selección. Todos los genotipos pertenecen al Programa de Mejoramiento de la Universidad Federal de San Carlos/RIDESA llamadas variedades RB. Se establecieron siete ensayos de campo con un diseño de bloques al azar con cuatro repeticiones. Los caracteres evaluados fueron producción de caña, contenido azucarero, producción de azúcar y contenido de fibra. Se aplicaron tres métodos estadísticos para obtener los estimados de repetitividad: análisis de varianza (ANOVA), componentes principales y análisis estructural. Los tres métodos presentaron un comportamiento similar para los tres caracteres. El valor estimado de repetitividad más bajo fue para contenido de sacarosa (r = 0.40), con una confianza cercana al 70\%, indicando un efecto ambiental mayor en este parámetro en estado de madurez temprana. El contenido de fibra y producción de caña mostraron una media del estimado de repetitividad justo arriba de 0.60, con una confianza cercana al 80\%. Por tanto, el comportamiento de los genotipos de caña de madurez temprana sugiere que por lo menos cuatro socas deberían ser evaluadas en este estado de selección para obtener un valor real de predictibilidad de 80\% de los caracteres considerados.
ALLO AND AUTO-COMPETITION IN SUGARCANE EXPERIMENTS

By

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KEYWORDS: Competition, Plot Shape.

Abstract

In Brazil, sugarcane experimental plots for genotype evaluation usually have 3 to 5 rows with 8 to 20 m in length. When an experiment has 5 rows, the central ones (R2, R3, R4) will be in auto-competition in both sides (AUTO) and the rows on the edge (R1 and R5) will be in auto-competition on one side and in allo-competition on the other (ALLO50, with parallel neighbour rows N1 or N5 of adjacent plots). To evaluate AUTO and ALLO50, the rows were individually harvested and weighed (kg per metre) in nine experiments with different environmental conditions as part of the IAC Sugarcane Breeding Program. Each experiment was composed of 5 commercial cultivars and 15 new clones replicated in three blocks. The results showed that the average weight of the five best genotypes at ALLO50 were superior by 4 to 6% compared to the averages at AUTO. Some genotypes show better performances when in ALLO50 than in AUTO, indicating that experiments should have the rows planted mainly in AUTO, since this is how they will be grown on a commercial scale. The superior performance at allo-competition has also been observed in other crops and is probably due to more efficient environmental exploration either by the aerial plant part or by the root system. The correlations between the adjacent rows in the AUTO position as well as those in the ALLO50 position with the respective neighbouring rows N1 or N5 were also evaluated. The correlations between production (free from genotype and block effects) were low in the first harvest but, in the fourth harvest and in ALLO50 condition, reached negative values up to –0.4, suggesting competition, i.e., competitive genotypes damage their less competitive neighbours, an undesired situation for the choice of genotypes that will be planted in AUTO.

Introduction

Sugarcane experimental plots in Brazil are usually planted with 3 to 5 rows with the outside row sometimes being in competition with other genotypes (allo-competition) and the inside rows competing with the same genotype (auto-competition).

On a commercial scale, sugarcane crops are planted in monoculture, and therefore the plants only experience auto-competition. In order to ensure that testing is efficient, it is important to establish if there are differential effects between the competition systems.

Other crops, e.g. maize and eucalyptus have demonstrated that allo-competition can increase the production per area, presumably through more efficient exploitation of the architecture of the roots or above ground plant parts (Perecin et al., 1977; Scarpinatti et al., 2009). It has also been shown that the yields of genotypes can change in relation to one another depending on whether they are grown in allo- or auto competition.
The objective of this work was to collect preliminary data regarding differences in sugarcane response to auto- and partial allo-competition systems.

Material and methods

The data were obtained in 2008 from nine previously harvested experiments from the Bonfim Mill, Guariba-SP-Brazil, as part of the IAC Sugarcane Breeding Program. The experiments were planted in a randomised block design with three replications containing 20 genotypes each (5 commercial cultivars and 15 new clones). The nine experiments included in the study are shown in Table 1.

Experiments were planted in five rows (R1, R2, R3, R4, and R5) eight or ten metres long with 1.4 or 1.5 metres between rows. R1 was adjacent to the R5 row of parallel plot (named N1) with a different genotype and R5 had an adjacent row of a different genotype (named N5) resulting in 50% of allo-competition (ALLO50). Rows R2, R3 and R4 were adjacent to the same genotype on both sides; thus, they were in auto-competition (AUTO).

Each row was harvested and weighed (kg per metre) individually, allowing separate evaluations of those in ALLO50 [(R1+R5)/2] and those in AUTO [(R2+R3+R4)/3]. Correlations between adjacent rows were also determined, including rows N1 and N5.

Results and discussion

The overall average of the production in kilograms of the cultivars in the 9 experiments showed an increase of 10% for rows in ALLO50 when compared to those in AUTO. The ratio (Ratio = ALLO50/AUTO), presented values ranging from 0.65 to 1.49. There were cultivars that had much higher production when in ALLO50, such as RB867515 (Ratio=1.13), SP83-2847 (Ratio=1.23), CTC15 (Ratio=1.25), IACSP95-5000 (Ratio=1.17). Other cultivars showed Ratio around 1, such as RB72454 (Ratio=0.94), RB855453 (Ratio=1.04), SP91-1049 (Ratio=1.07), CTC4 (Ratio=0.91). The differential Ratios of the genotypes suggest that it is not recommended to establish plots with data being taken from rows in allo-competition since the genotypes will not be planted in this arrangement on a commercial scale. Increased production in allo-competition also has been observed in other crops, (e.g. maize, eucalyptus) and has been attributed to more efficient utilisation of resources by either the roots or aerial part of the plant. The increase in production from allo-competitive plants indicates that mixed planting containing different genotypes might be beneficial.

The correlation of the weights between adjacent rows was also evaluated in AUTO (R2R3, R3R4) and ALLO50 (R1N1 and R5N5). In general, these correlations (free from the genotype and block effects) were low (Table 1), but predominantly negative, suggesting that there is some competition, even in AUTO.

In the fourth harvest and in the ALLO50 condition, the correlations achieved negative values up to –0.48, suggesting that more competitive genotypes may slightly damage their less competitive neighbours or take advantage of the low production of the adjacent row to increase their own. This situation is undesirable for choosing the genotypes that will be planted only in auto-competition. For this reason, it is not advisable to work with plots in which there is a predominance of rows in allo-competition (1 to 3 rows).

Conclusions

1. On average, the genotypes in allo-competition (50%) were 10% superior in relation to the same genotypes in auto-competition.

2. The correlations of the weights between adjacent rows generally is low, but predominantly negative, even in auto-competition, indicating some low competition.

3. Some competitive genotypes may damage or take advantage of their less competitive neighbours, across the years (situation not wanted for the choosing of genotypes that will be planted only in auto-competition).
4. The differential reactions of genotypes suggest that it is not advisable to establish research plots with data being taken from rows in allo-competition since the genotypes will not be planted in this arrangement on a commercial scale.

Table 1—Correlations (free from block and genotypes effects) between rows in allo-competition (50%) or in auto-competition, harvest at 2008, Bonfim Mill, Guariba-SP-Brazil.

<table>
<thead>
<tr>
<th>Year-season-harvest (experiments)</th>
<th>Correlations R1N1 (ALLO50)</th>
<th>Correlations R5N5 (ALLO50)</th>
<th>Correlations R2R3 (AUTO)</th>
<th>Correlations R3R4 (AUTO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008-S1-H1</td>
<td>-0.14</td>
<td>-0.25</td>
<td>-0.19</td>
<td>-0.18</td>
</tr>
<tr>
<td>2007-S1-H1</td>
<td>-0.13</td>
<td>0.01</td>
<td>-0.14</td>
<td>-0.06</td>
</tr>
<tr>
<td>2007-S2-H1</td>
<td>0.03</td>
<td>0.11</td>
<td>0.16</td>
<td>0.07</td>
</tr>
<tr>
<td>2007-S3-H1</td>
<td>0.21</td>
<td>0.28</td>
<td>0.07</td>
<td>-0.2</td>
</tr>
<tr>
<td>2006-S2-H2</td>
<td>-0.02</td>
<td>-0.05</td>
<td>-0.19</td>
<td>0.09</td>
</tr>
<tr>
<td>2005-S2-H3</td>
<td>-0.1</td>
<td>-0.03</td>
<td>-0.05</td>
<td>-0.02</td>
</tr>
<tr>
<td>2007-S1-H4</td>
<td>-0.48</td>
<td>-0.39</td>
<td>-0.24</td>
<td>-0.12</td>
</tr>
<tr>
<td>2007-S2-H4</td>
<td>-0.08</td>
<td>0</td>
<td>0.08</td>
<td>0.06</td>
</tr>
<tr>
<td>2007-S3-H4</td>
<td>-0.2</td>
<td>-0.41</td>
<td>0.01</td>
<td>0.06</td>
</tr>
</tbody>
</table>

S1=autumn; S2=winter; S3=spring; H1=first to H4=fourth harvest

REFERENCES


ALLO ET AUTO-COMPÉTITION DANS LES ESSAIS DE CANNE À SUCRE

Par

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MOTS-CLÉS: Concours, Formulaire Parcela.

Résumé

Au Brésil, les parcelles expérimentales de canne à sucre pour l’évaluation des génotypes sont habituellement de 3 à 5 lignes de 8 à 20 m. Quand un essai a cinq lignes, les rangs centrales (R2, R3, R4) seront en auto-compétition des deux côtés (AUTO). Par contre, les rangs des bords (R1 et R5) seront en auto-compétition d’un côté et en allo-compétition sur l’autre (ALLO50, avec les lignes parallèles voisines N1 ou N5 des parcelles adjacentes). Afin d’évaluer AUTO et ALLO50, les lignes étaient individuellement récoltées et pesées (kg par mètre) dans neuf essais situés dans
des conditions environnementales différentes, qui font partie du programme d’hybridation de l’IAC. Chaque essai était composé de 5 cultivars commerciaux et 15 nouveaux clones, en répétition de trois blocs. Les résultats ont montré que le poids moyen des cinq meilleurs génotypes en ALLO50 était supérieur par 4 à 6% comparé à la moyenne en AUTO. Quelques génotypes ont montré une meilleure performance en situation ALLO50 par rapport à AUTO. Cela démontre que les essais devraient avoir les rangs établis principalement en AUTO, puisque c’est de cette manière qu’ils sont plantés à l’échelle industrielle. La supériorité des performances en allo-compétition a aussi été observée dans d’autres cultures et est probablement due à une exploration plus efficiente de l’environnement soit par la partie aérienne ou par le système radiculaire. Les corrélations entre les rangs adjacents en position AUTO de même que ceux en position ALLO50 avec leurs rangs voisins N1 ou N5 ont aussi été évalués. Ces corrélations entre la production (exempte d’effets du génotype ou de bloc) étaient faibles lors de la première récolte. Toutefois, lors de la quatrième récolte, et en condition ALLO50, des valeurs négatives atteignant –0.4 ont été atteintes, suggérant la compétition. Les génotypes compétitifs endommageaient donc les génotypes voisins moins compétitifs, une situation non-désirée dans le choix des génotypes qui seront cultivés en AUTO.

ALO Y AUTO-COMPETICIÓN EN EXPERIMENTOS DE CAÑA DE AZÚCAR

Por

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PALABRAS CLAVES: Competición, Forma de Parcela.

Resumen

Los experimentos en Brasil en caña de azúcar para evaluar genotipos, generalmente tienen 3 a 5 filas de 8 a 20 m de largo. Cuando un experimento tiene 5 filas, las filas centrales (R2, R3 y R4) estarán en auto-competencia en ambos lados (AUTO) y las filas de las orillas (R1 and R5) estarán en auto-competencia a un lado y en alo-competencia en el otro lado (ALLO50, con filas paralelas vecinas N1 a N5 de las parcelas adyacentes). Para la evaluación de filas AUTO y ALLO50 fueron cosechadas invidiamente y pesadas (kg/m) en nueve experimentos de diferentes condiciones ambientales que son parte del Programa de Mejoramiento de IAC. Cada experimento se comparó con cinco cultivares comerciales y 15 nuevos genotipos repetidos en tres bloques. Los resultados mostraron que el promedio del peso de los cinco mejores genotipos en ALLO50 fueron superiores en 4 a 6% comparando los promedios de los AUTO. Algunos genotipos mostraron mejor comportamiento si su condición es ALLO50 que en AUTO, indicando que los experimentos deberían plantarse principalmente en AUTO ya que de esta forma es como se siembra comercialmente. El comportamiento superior en alo-competencia ha sido observada en otros cultivos que probablemente se deba a una eficiente exploración ambiental, ya sea en la parte aérea de la planta o por el sistema radical. Las correlaciones entre las filas adyacentes en la posición AUTO así como aquellas en ALLO50 con sus respectivas líneas vecinas N1 o N5 también fueron evaluadas. Las correlaciones en producción (libres de los efectos genotípicos y de bloque) fueron bajos en primer corte, pero en cuarto corte y en condición ALLO50 alcanzaron coeficientes negativos de hasta –0.4, sugiriendo competencia, por ejemplo de genotipos competitivos que dañan a los menos competitivos de las filas vecinas, situaciones no deseadas al escoger los genotipos que serían sembrados en AUTO.
COMMERCIAL YIELDS AND RAPID ADOPTION OF THE ECU-01 VARIETY IN ECUADOR

By

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KEYWORDS: Sugarcane Varieties, Commercial Cane Production, Variety Adoption.

Abstract
THE Ecuadorian variety ECU-01 was released in August 2007, after a 10 year period of clonal selection through four selection stages and evaluations in semi-commercial plots. The variety was derived from the clone ECSP98-169 selected from the cross between SP81-6215 × SP80-1816 performed in COPERSUCAR (CTC) in Brazil. During the selection process, evaluations were performed on sugar content, cane tonnage, and resistance to smut (Ustilago Scitaminea), mosaic (ScMV) and common rust (Puccinia melanocephala). Additionally, a participatory approach of selection was performed with the cane mill’s technicians in order to allow an effective selection. The variety presented averages of cane t/ha of 98 (TCH), sugar t/ha of 9.1 (TSH) and fibre of 13.1% throughout evaluations of stage IV in six localities in plant cane and two ratoons. These values were superior to Ragnar (80 TCH and 7.2 TSH) the leading variety in Ecuador. In commercial production plots in San Carlos Mill, cane plant and first ratoon ECU-01 were on average superior to Ragnar by 2.1 TSH during the 2008-2009 period. A year after its release (2008), the three main sugar mills in Ecuador registered more than 1500 ha planted with ECU-01, and in 2009 the same mills planted 2620 ha. Results from commercial fields during the 2008 harvesting season showed that ECU-01 is superior to Ragnar, CC85-92, CR74-250, B7678, C10571-73 and C87-51.

Introduction
Sugarcane production in the Rio Guayas Valley is dependent on one variety, Ragnar, with more than 70% coverage. This variety was introduced 60 years ago from Australia to Ecuador and has been in commercial production for at least 30 years. Local production has not increased in the past decades, and dependence on a single variety is a permanent risk for a sugar industry settled in tropical conditions.

On the other hand, sugarcane breeding contributes to increased productivity without an increase in growing costs, and disease and insect resistance even reduce the costs of growing the crop (Berding et al., 2004).

The main objective of the Ecuadorian Research Center (CINCAE) is to develop local varieties adapted to the tropical, low sunlight and heavy soil conditions. Support areas of research (plant pathology, entomology, soils and fertiliser and chemistry laboratories) were also established to develop technologies for adequate crop management.

The Ecuadorian varieties should show a combination of cane tonnage and sucrose contents and also fibre for co-generation.
The Varieties Program of CINCAE started in 1998. That year, a sugarcane collection was assembled to have genetic variation for future crosses. Because no facilities were available at this time, an agreement was signed with COPERSUCAR (CTC) from Brazil to make crosses, and the first selection series was planted with fuzz sent from Brazil.

After 10 years of evaluations and selection from Stage I to Stage IV and semi-commercial trials, the best clone was ECSP98-169. The selection trials were planted in several locations to evaluate the performance between locations and years (Castillo et al., 2007).

ECU-01 was named after the clone ECSP98-169 which is a progeny from a cross SP81-6215 × SP80-1816 performed in Centro de Tecnologia Canaviera-CTC (former COPERSUCAR) of Brazil. Fuzz was planted in September 1998 which provided plants to start the selection process from Stage I.

A total of 638 clones were selected to plant in Stage II, ending up with eight clones in Stage IV. After two years of evaluations, three clones were selected to plant in semi-commercial plots in San Carlos, Valdez and La Troncal mills. The best clone of these three was ECSP98-169, named ECU-01 (CINCAE, 2007).

**Results from commercial fields**

ECU-01 showed higher production of cane per hectare (TCH) than Ragnar in all evaluation trials along the selection stages. The same trend of production was observed in the 2009 harvesting season in all three main mills.

An analysis in plant cane and first ratoon of both varieties showed that ECU-01 is 2.1 tonnes sugar per hectare (TSH) higher than Ragnar on average from commercial fields during the 2009 harvesting season (Table 1).

This higher sugar tonnage might be related to the high tonnes cane per hectare (TCH) produced in the different commercial plots. ECU-01 can also be harvested at 12 months of age on average, while Ragnar is a 13 month variety in all commercial plots.

**Table 1**—Production of cane and sugar of ECU-01 in 2009 compared to variety Ragnar in San Carlos Mill.

<table>
<thead>
<tr>
<th>Production parameters</th>
<th>Variety</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ECU-01</td>
</tr>
<tr>
<td>Harvesting cycle (months)</td>
<td>12.46</td>
</tr>
<tr>
<td>TCH</td>
<td>107.25</td>
</tr>
<tr>
<td>Sugar/TC (kg)</td>
<td>96.32</td>
</tr>
<tr>
<td>TSH</td>
<td>10.33</td>
</tr>
</tbody>
</table>

The early ripening character of ECU-01 was analysed during the clonal evaluation data collection. Maturity curves were plotted to evaluate the sucrose accumulation through the months before harvesting. Figure 1 shows the differences between ECU-01 and Ragnar in the three main mills where evaluations were performed in semi-commercial fields. In all three cases, the Ecuadorian variety presents higher and earlier sucrose accumulation compared to Ragnar. Therefore, ECU-01 could be easily harvested at 12 months as the commercial fields are demonstrating in 2009.

Managers and farmers at the mills see the variety as important commercial material to diversify cane production in their units. Since the release of ECU-01 in 2007, there has been a rapid increase in commercial fields. The seed stock provided to the mills in 2006 allowed them to plant a total of 613.81 ha in 2007. This number of units increased to 2620.67 in year 2009 (Table 2) and it is expected to keep increasing its planting area in the coming years.
Fig. 1—Sucrose accumulation maturity curves for ECU-01 in three environments: (A) San Carlos, (B) Valdez, and (C) ECUDOS mills. Evaluation carried out in 2008.
Table 2—Number of hectares planted with ECU-01 per year. The release of the variety was September 2007.

<table>
<thead>
<tr>
<th>Year</th>
<th>Mill*</th>
<th>San Carlos</th>
<th>ECUDOS</th>
<th>Valdez</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td></td>
<td>215.0</td>
<td>168.5</td>
<td>230.4</td>
<td>613.8</td>
</tr>
<tr>
<td>2008</td>
<td></td>
<td>792.7</td>
<td>363.1</td>
<td>377.1</td>
<td>1532.8</td>
</tr>
<tr>
<td>2009</td>
<td></td>
<td>1184.7</td>
<td>500.0</td>
<td>936.0</td>
<td>2620.7</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>2192.4</td>
<td>1031.6</td>
<td>1543.4</td>
<td>4767.4</td>
</tr>
</tbody>
</table>

*Personal communication: Glenda Toala (ECUDOS mill), Walter Jara (Valdez Mill), and Edgar Sánchez (San Carlos Mill).

Conclusions

The newly released variety ECU-01 shows outstanding yields in the tropical lowland conditions of Ecuador. Its main feature appears to be its ratooning ability and early ripening. Sucrose accumulation starts at 11 months and the variety can be harvested at 12 months. This is the main advantage compared to Ragnar which is a 13 month variety. ECU-01 is superior to Ragnar with 2.1 TSH in plant cane and first ratoon crops. A rapid adoption is observed in the Ecuadorian industry of this new variety due to its good agronomic characteristics.

REFERENCES


RENDEMENT INDUSTRIEL ET ADOPTION RAPIDE DE LA VARIÉTÉ ECU-01 EN ÉQUATEUR

Par

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MOTS CLÉS: Variétés de Canne à Sucre, Production Industrielle de Canne à Sucre, Adoption des Variétés.

Résumé

La variété Équatorienne ECU-01 a été homologuée en août 2007, après 10 ans de sélection clonale constituée de quatre stades et des évaluations en parcelles semi-industrielles. La variété découle de la lignée ECSP98-169, sélectionnée à partir d’un croisement entre SP81-6215 x SP80-1816 effectué à COPERSUCAR (CTC) au Brésil. Durant le processus de sélection, des évaluations

**PRODUCCIÓN COMERCIAL Y RÁPIDA ADOPCIÓN DE LA VARIEDAD ECU-01 EN ECUADOR**

Por

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PALABRAS CLAVE: Variedades de Caña de Azúcar, Producción Comercial de Caña, Adopción de Variedades.

**Resumen**

LA VARIEDAD ecuatoriana de caña de azúcar (ECU-01) fue liberada en agosto de 2007, luego de un proceso de selección clonal a través de cuatro estados de selección y parcelas semicomerciales, con una duración de 10 años. Esta variedad fue derivada del clon ECSP98-169 proveniente del cruzamiento entre SP81-6215 × SP801816 realizado por COPERSUCAR (hoy CTC) de Brasil. Durante el proceso de selección se realizaron evaluaciones principalmente de contenido azucarero, producción de caña, resistencia a Carbón (*Ustilago scitaminea*), Mosaico (ScMV) y Roya (*Puccinia melanocephala*). Además, se realizaron evaluaciones participativas en la selección de clones, con el apoyo de técnicos de los ingenios, que permitieron una selección más efectiva. Esta variedad presentó promedios de producción de caña por hectárea (TCH) de 98 toneladas, con una producción de azúcar promedio de 9.1 toneladas por hectárea (TAH), y un promedio de fibra de 13.1%, en evaluaciones en Estado IV en seis localidades y durante tres cortes; superando a la variedad Ragnar, que es la variedad con la mayor área sembrada (66 %), que mostró promedios de 80 TCH y 7.2 TAH. En canteros comerciales del Ingenio San Carlos, en caña planta y primera soca superó con 2.1 TSH a Ragnar en el 2008–2009. Un año después de la liberación de la variedad ECU-01 (2008), los tres ingenios mas grandes del Ecuador registraron una superficie sembrada de 1500 hectáreas, y en el año 2009 alcanzó las 2620 ha. Los primeros resultados a nivel comercial obtenidos en la zafra 2008, indican que la nueva variedad mantiene su superioridad en comparación a la variedad Ragnar, CC85-92, CR74-250, B7678, C10571-73 y C87-51.
GENOTYPE BY ENVIRONMENT INTERACTION FOR YIELD IN SUGARCANE PERFORMANCE TRIALS: A COMPARISON OF FREQUENTLY USED MODELS

By

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KEYWORDS: Genotype-Environment Interaction, Sugarcane, Statistical Analysis, AMMI.

Abstract
The objective of this paper was to apply different multivariate statistical analysis, (cluster analysis, model of main effects additives and multiplicative interaction (AMMI), regression analysis of sites (GGE) and principal coordinates analysis (PCO)), to compare their utility and efficiency in the study of the genotype-environment interaction (GE) in sugarcane cultivars. Performance data of eighteen cultivars evaluated at four locations, in the south-eastern region of Cuba, was used in this study. The experimental design used in each trial was a randomised complete block. The evaluated variable was tonnes of cane per hectare. Analysis of variance showed that effects of genotype, environment and GE were highly significant. Cluster analysis discriminated between four locations, while the GGE method only generated three groups of environments. The biplot indicated that there were similar results between the AMMI and GGE model. The scatter point diagrams obtained from PCO analysis, however, revealed only limited agreement with the results obtained by the AMMI and GGE model. The G+GE captured by AMMI (50.2 %) and GGE (77.0 %) were both more adequate than PCO analysis in quantifying environment and genotype effects.

Introduction
The differential response of a genotype or cultivar for a given trait across environments is defined as the genotype × environment interaction (GE). If this GE is large, it may result in failure to differentiate performance of genotypes across environments, and it can reduce the precision of the selection across the environments.

Therefore, GE is an important and an essential component of plant breeding programs dedicated to cultivar development. Further, effective statistical analysis of yield trials can help breeders to make faster progress (Gauch, 2006).

The objective of the present study was to compare different multivariate statistical techniques for analysis of multi-environment sugarcane cultivar yield trials.

Materials and methods
Data from a multi-environment trial were analysed. The trial was carried out in the south-eastern region of Cuba at four locations across the sugarcane production zone (Table 1). Eighteen sugarcane cultivars released by the Cuban National Institute for Sugarcane Research (INICA) over the last 10 years were evaluated (Table 2). Experiments at each location were planted in a randomised block design using three replications. Cane yield (t/ha) for one cropping season was recorded.
Table 1—Information of the four experiment locations of the multi-environment trial.

<table>
<thead>
<tr>
<th>County</th>
<th>Name</th>
<th>Code</th>
<th>Year</th>
<th>Harvested (months)</th>
<th>Soil type</th>
<th>Annual Rainfall (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Santiago de Cuba</td>
<td>Paquito Rosales</td>
<td>PR</td>
<td>2006</td>
<td>16</td>
<td>Cambisol Eutrico</td>
<td>1156.7</td>
</tr>
<tr>
<td>Santiago de Cuba</td>
<td>Julio A. Mella</td>
<td>ME</td>
<td>2006</td>
<td>16</td>
<td>Acrisol Alúmico</td>
<td>1031.1</td>
</tr>
<tr>
<td>Granma</td>
<td>Enidio Díaz</td>
<td>ED</td>
<td>2006</td>
<td>16</td>
<td>Feozem Calcárico</td>
<td>1130.4</td>
</tr>
<tr>
<td>Guantánamo</td>
<td>Manuel Tames</td>
<td>MT</td>
<td>2006</td>
<td>16</td>
<td>Cambisol Eutrico</td>
<td>966.6</td>
</tr>
</tbody>
</table>

Table 2—Clones (genotypes) evaluated in the multi-environment trial.

<table>
<thead>
<tr>
<th>Code</th>
<th>Clone</th>
<th>Code</th>
<th>Clone</th>
<th>Code</th>
<th>Clone</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>B7274</td>
<td>G7</td>
<td>C86-531</td>
<td>G13</td>
<td>C90-501</td>
</tr>
<tr>
<td>G2</td>
<td>C128-83</td>
<td>G8</td>
<td>C87-632</td>
<td>G14</td>
<td>C90-530</td>
</tr>
<tr>
<td>G3</td>
<td>C323-68</td>
<td>G9</td>
<td>C88-380</td>
<td>G15</td>
<td>C90-647</td>
</tr>
<tr>
<td>G4</td>
<td>C86-12</td>
<td>G10</td>
<td>C89-250</td>
<td>G16</td>
<td>C91-356</td>
</tr>
<tr>
<td>G5</td>
<td>C86-156</td>
<td>G11</td>
<td>C89-559</td>
<td>G17</td>
<td>C92-325</td>
</tr>
<tr>
<td>G6</td>
<td>C86-503</td>
<td>G12</td>
<td>C90-317</td>
<td>G18</td>
<td>CP52-43</td>
</tr>
</tbody>
</table>

The 18 experimental cultivars were (G1), (G2), (G3), (G4), (G5), (G6), (G7), (G8), (G9), (G10), (G11), (G12), (G13), (G14), (G15), (G16), (G17) and (G18).

Statistical analysis

Repeated measures analysis of variance (ANOVA) was performed to determine the significance of the main effects of genotype and environment, as random effects, and the effect of genotype-environment interaction. With the residuals of GE, a multivariate statistical analyses for GE and phenotypic stability was carried out.

Multivariate statistical techniques

The analysis used for the study of GE interaction and phenotypic stability in sugarcane cultivars were: cluster analysis (Ghadery et al., 1980), additive and multiplicative interaction (AMMI) (Gauch, 2006), regression analysis of sites (GGE) (Yan et al., 2006), and principal coordinates analysis (PCO) (Westcott, 1987). All statistical analyses were performed using the Statistica system (StatSoft, 2003).

Results and discussion

Analysis of variance

Results of analysis of variance for the yield data are presented in Table 3, which gives an overall picture of the relative magnitudes of the genotype, environment, and GE variance. Locations were the most important source of variation, accounting for 65.2%. GE interaction accounted for 25.8% of total sum of squares.

Table 3—Analysis of variance and variance term estimates for cane yield.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Mean squares</th>
<th>Percent of total sum of squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location (L)</td>
<td>3</td>
<td>30345.6</td>
<td>** 59.1</td>
</tr>
<tr>
<td>Rep. (within L)</td>
<td>8</td>
<td>89.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Genotype (G)</td>
<td>17</td>
<td>813.9</td>
<td>** 9</td>
</tr>
<tr>
<td>GxL</td>
<td>51</td>
<td>780.6</td>
<td>** 25.8</td>
</tr>
<tr>
<td>Error</td>
<td>136</td>
<td>64.3</td>
<td>5.7</td>
</tr>
</tbody>
</table>

** indicate significant differences at p<0.01
Statistical analysis to study GE interaction effects and phenotypic stability

a) Cluster analysis

Mella was detected as the major contributing location to the GE interaction (Figure 1). This location is characterised by a different soil than at the others locations (Table 1). Removal of Mella from the analysis resulted in a single cluster, containing all other locations, with significance for GE interaction.

Fig. 1—Cluster dendogram showing the relationships among locations and their GE interaction effects for cane yield. Cluster analysis using Ward’s method algorithm.

b) AMMI and GGE models analysis

AMMI analysis indicated that the first multiplicative components explained 50.2% of the GE interaction (Figure 2). Enidio Díaz was detected as the location with the highest yield, with genotype G14 performing best at this location. On the other hand, Paquito Rosales showed the lowest average yield. The G5, G9 and G4 cultivars performed well over all locations.

Fig. 2—AMMI, Biplot: The genotype and environment means are shown on the abscissa, with a vertical line at grand mean. The principal component (PC) 1 scores are shown on ordinate.

The GGE model (Figure 3a) explained 77% of the variance of genotypes and GE interaction. The locations were grouped into three for the region in study: (i) Enidio Díaz, (ii) Mella and Paquito Rosales, and (iii) Manuel Tames. This result is different to the cluster analysis, which revealed significant differences between Mella and Paquito Rosales locations. Vertex genotypes for each location are the most responsive genotypes (Yan et al., 2006) and include G14 in Enidio Diaz; G10 and G5 in Mella and Paquito Rosales; and G17 in Manuel Tames.
Figure 3b shows the mean performance of genotypes (the line that passes through the biplot origin and the environment) and genotype stability (the line that passes through the biplot origin and the genotype), obtaining results similar to AMMI1 (Figure 2).

**Principal coordinates analysis**

In the low cycle (Figure 4a) and for the four locations in the study, the genotypes more distant to the centre of the diagram are G5, G9 and G4, and are regarded as the most stable cultivars. Also, genotypes G7, G1 and G10 are further from the centre, for the first three cycles of low yield. Nevertheless, G7 was more repeatable across all cycles, showing stability for discriminating environments and low yield.

For the high cycle (Figure 4b), the genotypes (G5 and G9) more distant to the centre in the last cycle, are the same as for the previous cycle. G14 was a winning genotype for the first three cycles, showing stability for high-yielding environments. AMMI and PCO analyses were very
similar for identifying G5, G9 and G4 cultivars, as the more stable cultivars. For G14, AMMI and GGE results partially do not agree with PCO. This genotype is mainly associated with high-yielding environments (Enidio Díaz).

The multivariate analyses AMMI and the regression analysis for sites (GGE) were similar to show genotype performance across environments, with differences in the contribution explained in terms of GE interaction variance (GGE>AMMI1). Both these models were better than PCO analysis in quantifying environment and genotype effects for cane yield and can be equivalent for gaining accuracy. Other models, like cluster analysis, did not show a clear tendency to group, and they are a poorer fit to the data observed. In our point of view, GGE and AMMI are ideal models for visualising patterns in yield-trial data.

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INTERACTIONS GÉNOTYPE-ENVIRONMENT POUR LE RENDEMENT CANNE DANS LES ESSAIS DE CANNE À SUCRE: UNE COMPARAISON DES MODÈLES FRÉQUEMMENT UTILISÉS

Par

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MOTS-CLÉS: Interactions Génotype-Environnement,
Canne à Sucre, Analyses Statistiques, AMMI.

Résumé
L’OBJECTIF de cette étude était d’évaluer les différentes analyses multivariables (analyse des conglomérats, modélisation additive et multiplicative de l’interaction (Modèle AMMI), analyse de régression des environnements (GGE) et analyse des coordonnées principales (PCO)), afin de comparer leurs utilités et leurs efficacité dans l’étude des interactions génotype-environnement (GE) des cultivars de canne à sucre. Les données de rendement en canne de dix-huit cultivars évalués dans quatre sites dans la région Sud-Est de Cuba, étaient utilisées pour cette étude. Le dispositif expérimental adopté pour chaque essai était un bloc randomisé. L’analyse de variance a démontré que les effets génotype, environnement et GE étaient hautement significatifs. L’analyse des conglomérats a distingué les quatre sites, alors que la méthode GGE en a distingué trois. Le
biplot a indiqué que les résultats pour les modèles AMMI et GGE étaient similaires. Un graphique d’éparpillement des points obtenu de l’analyse PCO, a toutefois révélé un accord limité entre les résultats obtenus par les modèles AMMI et ceux du GGE. Les G+GE obtenus par AMMI (50.2 %) et GGE (77.0 %) étaient tout deux plus précis que l’analyse PCO pour quantifier les effets environnement et génotype.

COMPARACIÓN DE MÉTODOS ESTADÍSTICO MULTIVARIADOS EN EL ESTUDIO DE LA INTERACCIÓN GENOTIPO AMBIENTE Y LA ESTABILIDAD FENOTÍPICA EN CAÑA DE AZÚCAR

Par

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PALABRAS CLAVES: Caña de Azúcar, Análisis Estadístico, AMMI.

Resumen

El objetivo del presente trabajo fue aplicar diferentes métodos estadísticos multivariados como el análisis de cluster, análisis de coordenadas principales (PCO), modelo de efectos principales aditivos e interacción multiplicativa (AMMI) y análisis de regresión de sitios (GGE), para comparar su utilidad y eficiencia en el estudio de la interacción genotipo-ambiente (IGA) y la estabilidad fenotípica en caña de azúcar. Los datos analizados corresponden a cuatro estudios multiambientales conducidos en la región sur oriental de Cuba, con 15 cultivares, sobre la variable tonelada de caña/ha. Se encontró predominio del efecto ambiental en la varianza total (65.2 %), seguido de la IGA (25.8 %). El análisis de cluster sugirió agrupamiento de las localidades, diferenciándose unas de otras, sin embargo, la agrupación realizada por el modelo GGE generó tres ambientes. Resultados similares mostraron los modelos AMMI y GGE en la descripción del patrón de comportamiento de la IGA y la estabilidad fenotípica de los cultivares, correspondiendo la mayor extracción de la varianza al biplot GGE2 (77.0 %), seguido del biplot AMMI1 (50.2 %). Al comparar los resultados de estos dos modelos con el análisis de PCO, no se encontró total coincidencia en sus resultados, por lo que los dos primeros resultaron más adecuados.
MANAGED INITIATION OF SUGARCANE FLOWERING IN KHUZESTAN-IRAN: A STUDY OF DIFFERENT PHOTOPERIODIC TREATMENTS

By

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KEYWORDS: Flowering Initiation, Photoperiod, Sugarcane, Breeding program, Day length reduction.

Abstract

MANAGED initiation of flowering is a priority of the sugarcane breeding program in Iran, as sugarcane does not flower under natural conditions in this region. Two photoperiod treatments (long and short) were studied at the Sugarcane Research Centre of Khuzestan province. A sample of 18 cultivars from the sugarcane germplasm collection was classified in three groups according to flowering behaviour at their origins. The treatments and natural photoperiods with control of temperature and humidity were effective to induce flowering in different sugarcane cultivars. High flowering cultivars responded less, while the short treatment cycle (104 days) guaranteed the more intense flowering. The results of the experiments suggest a method for artificial initiation of flowering and an expansion of the photoperiod facilities.

Introduction

Khuzestan is located in the south west of Iran and sugarcane areas are between 31–32°N latitude and 48°E longitude at an elevation of 7 to 80 m above sea level. Daily average maximum temperatures in January and July are 8° and 46.5°C, respectively. Annual evaporation is about 3000 mm and relative humidity is low. Most rainfall occurs between November and April with an annual average of only 240 mm. Because of hot and dry weather, sugarcane is fully irrigated and, with suitable agronomic practices, high yields are achievable from plantations.

Khuzestan has been using old varieties and needs new varieties that are adapted to the conditions and are resistant to diseases such as smut and mosaic.

One of the methods to produce genetic variability is hybridisation of the genetic material in germplasm collections, for which flowering is essential. Climatic and natural photoperiodic conditions of the Khuzestan province are not conducive to flowering in sugarcane. Thus, artificial initiation is necessary.

Flowering is initiated by gradually reducing day length of between 12:30 h and 12:45 h by 30–60 s. (Alexander, 1973; Brett and Harding, 1974). We have established methodology for the artificial initiation of flowering for the sugarcane breeding program in Iran, and this is discussed in the present paper.

Materials and methods

The studies were conducted between September 2003 and March 2007, in the Sugarcane Research Centre belonging to the Sugarcane & By Products Development Co.
The photoperiod and glasshouse used for the experiments were built in 2000, and consisted of one dark room of $5 \times 4 \times 6$ m and a crossing house $5 \times 10 \times 7$ m constructed from local material. Night temperature inside the dark room was regulated between 19–22°C and maximum temperature in the glasshouse was maintained between 28–32°C depending on the season. The required relative humidity (70–85%) was regulated by using a semi-automatic system. Eighteen cultivars were chosen from the germplasm collection, and classified according to their flowering behaviour in their countries of origin and the evaluation of the germplasm collection in Cuba (Perez et al., 1997) (Table 1). They were planted in plastic pots of 25 L capacity and five stalks were retained in each pot.

Table 1—Cultivars used in the experiments.

<table>
<thead>
<tr>
<th>Low flowering (&lt;15%)</th>
<th>Medium flowering (15–25%)</th>
<th>High flowering (&gt;25)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP70-321</td>
<td>Co1148</td>
<td>CP57-614</td>
</tr>
<tr>
<td>CP72-355</td>
<td>CP48-103</td>
<td>CP65-315</td>
</tr>
<tr>
<td>C88-393</td>
<td>CP65-392</td>
<td>CP82-1592</td>
</tr>
<tr>
<td>Cristalina</td>
<td>CP69-1062</td>
<td>CP72-2086</td>
</tr>
<tr>
<td>N55-805</td>
<td>SP70-1143</td>
<td>Ja64-19</td>
</tr>
<tr>
<td>NCo310</td>
<td>SP80-1587</td>
<td>L62-96</td>
</tr>
</tbody>
</table>

Initiation of flowering in the northern hemisphere occurs between September and October (Moore and Heinz, 1972; Allam et al., 1977). Treatments were initiated on July 23, five weeks before September. To guarantee enough time for flowering to occur, the period was extended to December 10. Day length in Khuzestan varies from 13:51:00 to 10:09:30 h, with an average reduction daily of 94 seconds.

According to the day length and daily reduction in the period of the experiment and also the available information from different countries with similar latitudes for flowering (Anon., 1971; Anon., 1977), two artificial photoperiod treatments, one with 104 days and another with 141 days, were established. Two natural photoperiod treatments, one inside the glasshouse and another in natural farm conditions were carried out as controls.

**Short treatment (104 days)**
This treatment began on July 23 with day length shortening to 12:30:00 hours, using more darkness, and continued till September 9, when the natural photoperiod attained the length desired of 12:30:00 hours. The treatment finished on November 3 and the necessary hours of artificial light were supplied to decrease the day length to 12:00:00 hours.

**Long treatment (141 days)**
This treatment was similar to the previous treatment but the time was extended to December 10 by decreasing the day length to 11:23:00 hours, with extension lighting, by means of two lines of three fluorescent 500 watt and two lines of three incandescent 200 watt light bulbs to guarantee the uniformity of light distribution.

Photoperiod treatments started by moving the trolleys into the dark room by means of a semiautomatic control system on 23 July, half an hour after Almanac sunset, and pulling out the pots from the photoperiodic house to glasshouse after sun rise. This experiment was repeated over four years (2004–2007).

Only the intensity of flowering (%) was evaluated in the experiments according to Jorge et al. (2002) and Hamdi et al. (2003). The statistical analysis was based on use of contingency tables (Chi square), applied to the treatments and cultivars and their interaction.
The influence of maximum and minimum temperatures, thermal oscillation and relative humidity inside and out of the glasshouse were studied and recorded throughout the experiments using automatic instruments.

The artificial photoperiod was compared with natural flowering for the three levels of flowering: group 1 (high flowering, >25%); group 2 (medium flowering 1–25%) and group 3 (null flowering, < 1%).

**Results and discussion**

The short photoperiod treatment resulted in the best flowering overall and had the biggest impact on the cultivars of low flowering propensity, an increase of 19%. This is comparable to the results of Miller and Lii (1995) who showed that short treatments are more effective for the initiation of flowering than continuous and longer treatments (Table 2).

### Table 2—Flowering percentage for the various treatments.  

<table>
<thead>
<tr>
<th>Photoperiod treatment</th>
<th>Flowering percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Short</td>
<td>56.6</td>
</tr>
<tr>
<td>Long</td>
<td>56.3</td>
</tr>
<tr>
<td>Internal control</td>
<td>54.8</td>
</tr>
<tr>
<td>External control</td>
<td>0</td>
</tr>
</tbody>
</table>

The long photoperiod treatment (141 days) had an inhibitory effect on cultivars of medium and scarce flowering. Nuss and Berding (1999) indicated the inductive period of cultivars becomes shorter in latitudes greater than 30°.

The cultivars of high flowering propensity responded minimally to the photoperiod treatments, probably because their flowering is influenced by other factors such as temperature and humidity.

The characteristics of the managed photoperiod, or day length and daily reduction, during the time of flowering initiation in Khuzestan, are within the ranges of other investigations which also were successful in artificial initiation from flowering.

Miller and Lii (1995), in Louisiana, beginning with 12:21 hours followed by a daily descent between 60–105 seconds achieved initiation in clones of scarce flowering.

**Effect of climatic variables on flowering**

The parameters *Wilks Lambda* and *F* of the Discriminant Analysis (results not presented) indicated that the variables that better discriminated between the groups were the relative humidity (HRELAT) and the thermal oscillation (OSC_TEMP), while the temperatures (TMIN and TMAX) did not enter in the model, although they are included in an indirect way because of the close relation that they keep with the thermal oscillation.

The bigger contrast was in the maximum temperature which differs from minimum temperature and relative humidity according to Coleman (1962, 1963) who said that, in latitudes far from the Equator; the temperature acquires more importance for the initiation of the flowering than photoperiod, which agrees totally with the results shown in this paper.

The importance of these variables in the initiation of flowering has been reported by numerous researchers (Clements and Awada, 1967; Miller and Lii, 1995, Berding, 2005). The discriminating model made possible the correct classification of 100% of the cases and the distances between groups were significant.
Conclusions

1. Short artificial photoperiod treatments (104 days) produce more flowering than long treatments (141 days) with a bigger impact on the cultivars of low flowering propensity.

2. Cultivars of high flowering responded less to the treatments with artificial initiation of flowering and their potential in this regard is largely influenced by other factors.

3. The climatic variables which have more effect in the initiation of flowering in Khuzestan are the relative humidity and the thermal oscillation. They have a bigger importance than the day length and the daily declination.

REFERENCES


PILOTAGE DE L'INITIATION DE LA FLORAISON DE LA CANNE À SUCRE EN KHUZESTAN-IRAN: UNE ÉTUDE DE DIFFÉRENTS TRAITEMENTS PHOTOPÉRIODIQUES

Par

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MOTS CLÉS: Initiation de la floraison, Photopériode, Canne à Sucre, Programme D’amélioration Génétique, Réduction de la Photopériode.

Résumé

Le pilotage de l’initiation de la floraison est une priorité pour le programme d’hybridation génétique de la canne à sucre en Iran, la canne ne fleurissant pas dans des conditions naturelles dans cette région. Deux traitements photopériodiques (long et court) ont été étudiés au Sugarcane Research Centre de la province de Khuzestan. Un échantillon de 18 cultivars de la collection de la canne à sucre a été classifié en trois groupes selon leurs comportements floraux dans leurs centres d’origine. Les traitements de photopériodes en combinaison avec le contrôle de la température et d’humidité, étaient efficaces pour induire la floraison chez différents cultivars de canne à sucre. Les cultivars avec un fort taux de floraison répondaient moins bien, alors que le traitement de cycle court (104 jours) garantissait une floraison plus intense. Les résultats de cet essai offrent une méthode pour l’initiation de la floraison artificielle et l’expansion des infrastructures photopériodiques.
INICIACIÓN ADMINISTRADO O FLOR DE CAÑA DE AZÚCAR
IN KHUZESTAN-IRÁN: UN ESTUDIO DE DIFFERENT TRATAMIENTOS PHOTOPERIODIC

Par

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PALABRAS CLAVES: Inducción de la Floración, Fotoperiodo, Caña de Azúcar, Programa de Mejora, Reducción Diaria.

Resumen
LA INDUCCIÓN artificial de la floración constituye una de las prioridades del Programa de Mejoramiento Genético de la Caña de Azúcar en Irán, ya que naturalmente la caña no florece. En el Centro de Investigaciones de la Caña de Azúcar en la provincia Khuzestán, se estudiaron dos variantes de fotoperiodo artificial con diferentes combinaciones de duración del día y reducción diaria, así como ciclos de exposición, en una muestra de 18 variedades de la colección de germoplasma, agrupadas en tres categorías de acuerdo a los niveles de floración en sus países de origen. Los tratamientos utilizados y el fotoperiodo natural con control de la humedad y la temperatura fueron efectivos en la inducción de la floración. Las variedades de alta floración fueron las de menor respuesta, mientras que los tratamientos cortos (104 ciclos) garantizaron la mayor intensidad de la floración. Se recomienda una metodología para la inducción artificial de la floración, así como la ampliación de la casa de fotoperiodo como aplicación práctica del trabajo.
IMPROVING THE HARVEST SEASON BASED ON THE MATURITY IN FOUR SUGARCANE GROWING REGIONS IN CUBA

By

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KEYWORDS: Harvesting Season, Genotypes, Sugarcane Maturation.

Abstract

CLIMATE change, which has resulted in global warming, has affected cane production and altered the period of harvest. New investigations are necessary to determine the critical periods of harvest, based on the interactions resulting from the combination of different genotypes and land-ecosystems. Forty eight trials were conducted in four contrasting sugarcane growing regions of Cuba with three varieties – C 1051-73 (early), C 86-12 (mid-season), My 5514 (late-season) that differ in ripening period. A combination of month of harvest and ages from nine to twenty-four months, in two crops, soil types and ratoon crops for ripening characteristics were studied. At the age of 13 months (typical harvest time in Cuba), the studied regions produced significant differences, higher than those relating to varieties. Consequently, the harvesting season must be reorganised. The Centre-Eastern Region was more efficient, with any variety, while the Eastern Region showed a better behaviour of genotypes in the March-October period.

Introduction

Productivity of sugarcane in Cuba has regressed as a consequence of global warming, mainly due to the long periods of drought and the change in rainfall pattern. The sugar industry has developed a process of reorganisation, which includes the identification of the best lands to produce sugarcane and the optimisation of the harvest. It is necessary to find the optimal dates to begin the harvest season according to agro-ecological zones, as well as the sugarcane cultivar that can be planted. It is also important to know the possible extension of the crop period, if soil and climatic conditions are favourable.

It is necessary to study the ripening pattern of the main cultivars out of the periods traditionally used to harvest them.

Materials and methods

To meet the proposed objectives, 48 experiments at four cane contrasting regions of the country (west, centre-west, centre-east, east) were established over three crop cycles (plant cane, first and second ratoon), harvested during the whole year, and combining crop age from nine to twenty-four months. Three varieties were studied, C 1051-73, C 86-12 and My5514, classified as early-ripening, intermediate-ripening and late-ripening respectively over the normal harvesting period spanning from November to April. The variable studied was the evolution of sucrose using uni- and multi-variant analyses.

Results and discussion

The best period to harvest the cane according to the historical rainfall distribution is between November and April, when only 14–26% of the total volume of rains is received at the four regions studied (Figure 1).
With an increase in the volume of cane, which will entail a lengthening of the harvest season, an earlier harvest would not be possible, whereas delaying harvest until June is achievable except in the western region, and further until August in the Centre-Eastern and Eastern region (Figure 1).

During the first two months (November and December), sucrose content of variety C 1051-73 is low in the Western and Eastern sectors, and it would be reasonable to delay harvest until January (Figure 2). In the Western region, sucrose content declines from May while in the Centre-West, the variety can be harvested from November until June.
In the Eastern region, the variety can be harvested until August because of the lower rainfall compared to the other sectors.

Sucrose accumulation for the intermediate variety, C86-12, is strongly influenced by environmental conditions. In the Central-Eastern region, it can be harvested early in the season from November to January (Figure 3). Similarly, in the Eastern zone, C1015-73 demonstrates earliness of ripening and it can be harvested from November to March (Figure 2).

Fig. 3—Dynamics of maturation C86-12 variety.

In the Eastern and Western zone, it is inappropriate to harvest My 5514 at the start of the harvest. Its harvest can delayed further in the Eastern region, which confirms previous observation (Milanes and Tejero, 1995) (Figure 4)

Fig. 4—Pattern of sucrose accumulation for variety My5514.
The environmental component of variation exceeded by far the genotypic effect (Table 1) and is highest in May and August, which is in agreement with Bernal (1986), González (1995), and Jorge et al., (2008).

Varieties show specific suitability to harvest dates in the different areas and should be managed individually.

Additionally, a wider range of varieties can be exploited in March in a wider range of environments. Stable varieties are more difficult to obtain.

Table 1—Components of variance for sugar content.

<table>
<thead>
<tr>
<th>Month</th>
<th>$\sigma^2_G$</th>
<th>$\sigma^2_Z$</th>
<th>$\sigma^2_{GE}$</th>
<th>$\sigma^2_e$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov</td>
<td>1.64 ± 1.77</td>
<td>3.15 ± 3.28</td>
<td>0.81 ± 0.46</td>
<td>0.33 ± 0.06*</td>
</tr>
<tr>
<td>PVT</td>
<td>27.66</td>
<td>57.32</td>
<td>10.21</td>
<td>4.82</td>
</tr>
<tr>
<td>Dec</td>
<td>0.26 ± 0.34</td>
<td>0.95 ± 1.02</td>
<td>0.27 ± 0.20</td>
<td>0.37 ± 0.07*</td>
</tr>
<tr>
<td>PVT</td>
<td>16.05</td>
<td>54.41</td>
<td>13.12</td>
<td>16.62</td>
</tr>
<tr>
<td>Jan</td>
<td>0.43 ± 0.45</td>
<td>1.87 ± 1.84</td>
<td>0.04 ± 0.10</td>
<td>0.46 ± 0.09*</td>
</tr>
<tr>
<td>PVT</td>
<td>14.77</td>
<td>66.75</td>
<td>4.37</td>
<td>14.11</td>
</tr>
<tr>
<td>Feb</td>
<td>0.34 ± 0.36</td>
<td>0.93 ± 0.93</td>
<td>0.08 ± 0.09</td>
<td>0.27 ± 0.05*</td>
</tr>
<tr>
<td>PVT</td>
<td>20.17</td>
<td>58.86</td>
<td>6.68</td>
<td>14.12</td>
</tr>
<tr>
<td>Mar</td>
<td>0.42 ± 0.63</td>
<td>0.26 ± 0.57</td>
<td>0.79 ± 0.51</td>
<td>0.66 ± 0.13*</td>
</tr>
<tr>
<td>PVT</td>
<td>24.23</td>
<td>24.42</td>
<td>27.52</td>
<td>23.83</td>
</tr>
<tr>
<td>Apr</td>
<td>0.00 ±</td>
<td>1.09 ± 1.62</td>
<td>1.77 ± 0.93</td>
<td>0.25 ± 0.05*</td>
</tr>
<tr>
<td>PVT</td>
<td>10.34</td>
<td>48.26</td>
<td>35.00</td>
<td>6.39</td>
</tr>
<tr>
<td>May</td>
<td>0.24 ± 0.28</td>
<td>3.54 ± 3.44</td>
<td>0.15 ± 0.12</td>
<td>0.26 ± 0.05*</td>
</tr>
<tr>
<td>PVT</td>
<td>6.16</td>
<td>84.77</td>
<td>3.67</td>
<td>5.39</td>
</tr>
<tr>
<td>Jun</td>
<td>0.69 ± 0.98</td>
<td>3.79 ± 4.05</td>
<td>1.16 ± 0.71</td>
<td>0.80 ± 0.16*</td>
</tr>
<tr>
<td>PVT</td>
<td>13.54</td>
<td>62.24</td>
<td>13.89</td>
<td>10.33</td>
</tr>
<tr>
<td>Jul</td>
<td>2.58 ± 3.08</td>
<td>12.40 ± 12.6</td>
<td>2.59 ± 1.38</td>
<td>0.50 ± 0.10*</td>
</tr>
<tr>
<td>PVT</td>
<td>15.70</td>
<td>71.96</td>
<td>9.94</td>
<td>2.40</td>
</tr>
<tr>
<td>Aug</td>
<td>1.52 ± 1.53</td>
<td>19.73 ± 18.98</td>
<td>0.50 ± 0.41</td>
<td>0.97 ± 0.19*</td>
</tr>
<tr>
<td>PVT</td>
<td>6.69</td>
<td>87.16</td>
<td>2.39</td>
<td>3.75</td>
</tr>
</tbody>
</table>

$\sigma^2$: Component of variance g, genotype, z. zone, ge. genotype x environments, e. error

* Precise Estimate if ES ≤ 2 $\sigma^2$ PVT. Percentage of total variation

It is evident that the major effect of the zones is associated on one hand with the chemical properties of the soils, the most significant of which are nitrogen and potassium available in the first horizon, as well as the acidity.

On the other hand, to the climate elements, minimum temperature and relative humidity, variables that account for more than 34% of the total variation in the first component (Table 2).

Other factors that contribute to the variation include the organic matter content, available phosphorus and accumulated rains four and five months prior to the harvest.
Table 2—Results of the principal component analysis.

<table>
<thead>
<tr>
<th></th>
<th>Comp. 1</th>
<th>Comp. 2</th>
<th>Comp. 3</th>
<th>Comp. 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>4.178</td>
<td>2.425</td>
<td>1.566</td>
<td>1.444</td>
</tr>
<tr>
<td>% Contribution</td>
<td>34.8</td>
<td>55.0</td>
<td>68.1</td>
<td>80.1</td>
</tr>
<tr>
<td>Vector</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pol % Cane</td>
<td>–0.046</td>
<td>0.632</td>
<td>0.016</td>
<td>0.424</td>
</tr>
<tr>
<td>t cane/ha</td>
<td>0.184</td>
<td>0.884</td>
<td>0.034</td>
<td>–0.090</td>
</tr>
<tr>
<td>t Pol/ha</td>
<td>0.163</td>
<td>0.957</td>
<td>0.035</td>
<td>0.060</td>
</tr>
<tr>
<td>Minimum</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>temperature</td>
<td></td>
<td></td>
<td></td>
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<tr>
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<td>0.402</td>
<td>–0.088</td>
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<tr>
<td>Cumulative</td>
<td>–0.025</td>
<td>0.030</td>
<td>0.064</td>
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</tr>
<tr>
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<td>0.031</td>
<td>0.065</td>
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</tr>
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<td>–0.869</td>
<td>–0.031</td>
</tr>
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<td></td>
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<tr>
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<td>–0.207</td>
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</tr>
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<td>potassium</td>
<td></td>
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The characterisation of the regions from the functions of components 1 and 2 (Figure 5) enabled the differentiation of the western and eastern regions and the central localities, which represent the best agro-climatic potential. The Central regions were those that contained most of nitrogen and available potassium.
Conclusions

1. Varieties displayed specific adaptation to harvest periods in the different sectors and should be managed individually.

2. Higher Pol % cane was observed at in the East-Centre zone and Western zone at the start of harvest (November–January), compared to the Eastern region. It would be appropriate to start harvest in the East-Central and Western zones.

The environmental effect contributed more to the total variation, and it was associated with the levels of nitrogen and potassium in the first horizon, the acidity of the soil, the minimal temperature and the relative humidity.

REFERENCES


PROGRAMMATION DE LA SAISON DE RÉCOLTE DE LA CANNE À SUCRE PAR RAPPORT À LA MATURITÉ DANS QUATRE RÉGIONS DE CUBA

Par

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MOTS CLÉS: Saison de Récolte, Génotype, Maturation de la Canne à Sucre.

Résumé

Le changement climatique a eu pour conséquence, le réchauffement global qui a affecté la production de la canne à sucre et a perturbé la saison de récolte. De nouvelles études sont nécessaires pour déterminer les périodes critiques de la récolte, basées sur les interactions résultant de la combinaison de différents génotypes et de l’écosystème terrien. Quarante-huit essais ont été établis dans quatre régions contrastées de canne à sucre au Cuba avec trois variétés – C 1051-73 (début), C 86-12 (milieu), My 5514 (fin) qui diffèrent en leur période de maturité. Une combinaison mois de récolte, âges de récolte de 9 à 24 mois, deux saisons de récolte, type de sol et repousses, par rapport aux profils de mûrissement étaient étudiés. À l’âge de 13 mois (période typique pour la récolte au Cuba), les régions ont démontré des différences significatives pour le mûrissement, plus importantes que celles occasionnées par les variétés. En conséquence, la saison de récolte devrait être réorganisée. L’effet du mûrissement était plus prononcé pour la région Centre-Est quelle que soit la variété, alors que les génotypes se sont mieux distinguées dans la région Est pendant la période mars-octobre.

MEJORAMIENTO DE LA ÉPOCA DE COSECHA BASADOS EN LA MADURACIÓN EN CUATRO REGIONES CAÑERAS DE CUBA

Par

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PALABRAS CLAVES: Época de Corte, Genotipos, Maduración de la Caña.

Resumen

Los cambios climáticos causantes del caliento global han afectado la producción y alterado el periodo de cosecha de la caña. Nuevas investigaciones son necesarias para determinar el periodo crítico de cosecha, basándose en los resultados de la interacción de diferentes genotipos y ecosistemas. Se condujeron un total de 48 ensayos en cuatro regiones cañeras cubanas contratantes con tres variedades que difieren en su periodo de maduración: C1051-73 (temprana), C86-12 (mediana), My5514 (tardía). Una combinación de mes de cosecha y edades entre nueve y 24 meses, en dos cortes, dos tipos de suelos y dos socas fueron estudiadas para madurez. A los 13 meses (periodo típico de cosechas en Cuba), las regiones estudiadas produjeron un efecto significativo y mayor al dependiente de variedades. Basados en ello, la época de corte debe ser reconocida. La región Centro-Oriental fue más eficiente con cualquier variedad, mientras que la región Oriental mostró mejor comportamiento varietal en el periodo marzo–octubre.
A NEW NOBILISATION SYSTEM IN SUGAR CANE (SACCHARUM SPP.)

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KEYWORDS: Sugarcane, Nobilisation, Chromosome Number.

Abstract
A new nobilisation system (NSN) in sugarcane (Saccharum spp.) is presented to compare with the traditional style of nobilisation (TSN). A group of parents with 2n+n chromosomes has been used to transmit this character to their progenies. The system has increased the chromosome numbers in some parents of our breeding program. We suggest a new nobilisation system in combination with the traditional one in order to increase the genetic base of sugarcane cultivars in any breeding program.

Introduction
The sugarcane breeding programs in most countries from the beginning of the 20th century, up to the present, have been performing hybridisation processes in a Traditional Style of Nobilisation (TSN) using a few original varieties of Saccharum officinarum, S. spontaneum, and complex hybrids from a similar genetic background.

Therefore, most of the current commercial varieties have a similar genetic base (Campo-Zabala and Pérez Oramas, 2004). The special cytogenetic behaviour of the hybrids between S. officinarum and S. spontaneum throughout generations (G) of nobilisation with 2n female gametes with duplicated number of chromosomes has not been exploited because of the reduced parental material and the use of the conventional crossing system (Price, 1958).

Sugarcane breeders are still searching for complex hybrids with better commercial characteristics. Therefore, the 2n gametes system has not been exploited in all its magnitude.

The aim of this paper is to promote the use of parents with 2n+n genetic endowment to apply in a new nobilisation system to help increase the genetic base in sugarcane breeding programs.

Materials and methods
Information on cytogenetic studies of the Cuban and introduced varieties during sugarcane nobilisation, parental ancestors, commercial varieties, and their progenies was analysed. In addition, results of breeding programs of the main sugarcane countries were compared, including crosses evaluated in different phases of selection, among 2n+n genotypes, commercial varieties and n+n parents (Jorge et al., 2002).

Results and discussion
Varieties from the series POJ from Java were the first commercial hybrids obtained in the world (Figure.1), especially POJ2878, which became, with its relatives, one of the most used parents up to the present. Most sugarcane commercial varieties around the world share their origin due to a continuous use of similar parental materials in the breeding programs by means of a Traditional Style of Nobilisation (TSN). Therefore, most current commercial varieties have a narrow genetic base (Walker, 1987; Campo-Zabala and Pérez, 2004).
Fig. 1—Traditional style of nobilisation (TSN) to obtain varieties of POJ series.

The commercial varieties in production have to be replaced frequently, either for their poor productive stability, or for the high incidence of diseases and insect pests. However, there have been genetic advances which can not be ignored such as the quality of the juice, sucrose percentage, vigour, etc. obtained from TSN.

Results from Java (Bremer, 1962) and Cuba (Campo-Zabala and Pérez, 2004) showed that selecting parental materials after an evaluation of their ancestors (genealogy), origins and chromosomal numbers of type 2n+n made possible a practical use of the New System of Nobilisation (NSN) (Figure 2).

Fig. 2—New style of nobilisation (NSN) for sugarcane.
The basis of the NSN method is to use 2n+n complex hybrids, either as female or male parents, combining with wild relatives, rather than traditional forms of *S. officinarum* and *S. spontaneum*. The benefits of this method are to increase the chromosome number until a generation (G) is reached with good agronomic performance that a breeder is looking for.

The development and application of the NSN in Cuba has allowed selecting a group of parental clones with 2n+n chromosome number. These materials are being used in the sugarcane improvement program, in order to obtain parents with increased number of chromosomes to enrich the genetic base of the future commercial varieties. Table 1 shows several combinations with 2n+n genotypes obtained in the Cuban breeding program.

### Table 1—Crosses frequently inducing production of 2n+n progenies.

<table>
<thead>
<tr>
<th>Crossings</th>
<th>Seedlings</th>
<th>Clones selected</th>
</tr>
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<tbody>
<tr>
<td>My5774 x C90-178</td>
<td>262</td>
<td>5</td>
</tr>
<tr>
<td>My5774 x C90-176</td>
<td>265</td>
<td>1</td>
</tr>
<tr>
<td>My5764 x My5777</td>
<td>292</td>
<td>11</td>
</tr>
<tr>
<td>51 NG 91 x C90-178</td>
<td>339</td>
<td>18</td>
</tr>
<tr>
<td>CSG222-92 x CP63-69</td>
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<td>3</td>
</tr>
<tr>
<td>Geel Muntok x US56-15-8</td>
<td>210</td>
<td>5</td>
</tr>
<tr>
<td>Ja55-488 x C90-176</td>
<td>63</td>
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</tr>
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<td>Q50 x My5774</td>
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</tr>
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<td>C90-176 x C90-178</td>
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</tr>
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<td>CSG489-92 x B49119</td>
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<td>6</td>
</tr>
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<tr>
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<td>CSG227-92 x Ja64-19</td>
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<td>Ja55-488 x Ja64-19</td>
<td>96</td>
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<td>51 NG 91 x My5764</td>
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<td>2</td>
</tr>
<tr>
<td><strong>Total: 20</strong></td>
<td><strong>2,751</strong></td>
<td><strong>87</strong></td>
</tr>
</tbody>
</table>

### Conclusions

The use of 2n+n genotypes and New Style of Nobilisation (NSN) facilitates the increase of the genetic base to improve the use of current germplasm in sugarcane. The system allows the introgression of new wild genes that provide progenies with better disease resistance and adaptation to different stress conditions. In addition, introduced varieties and a group of complex hybrids from the Cuban sugarcane germplasm allowed the development of the NSN and to establish the new hybridisation system. Further, at least 40 parental materials were proven to transmit 2n+n chromosomes to their progenies which enable the identification of crosses with 2n+n in the breeding program.

### REFERENCES

PROCEDIMIENTO INNOVADOR EN LA NOBILIZACIÓN DE CAÑA DE AZÚCAR (Saccharum spp.)

Par

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PALABRAS CLAVE: Caña de Azúcar, Nobilización, Número Cromosómico.

Resumen
UN NUEVO sistema de nobilización (NSN) en caña de azúcar (Saccharum spp.) es presentado para comparar con el estilo tradicional (TSN). Un grupo de parentales con número cromosómico 2n+n se han usado para trasmitir este carácter a sus progenies. El sistema ha ayudado a incrementar el número cromosómico en algunos parentales de nuestro programa de mejoramiento genético. Sugerimos el uso del nuevo sistema en combinación con el sistema tradicional para incrementar la base genética de los cultivares que se desarrollan en un programa de mejora.
EVALUATION OF FUNCTIONAL MICROSATELLITE MARKERS FOR SUGARCANE POLYCROSS PATERNITY ANALYSIS

By

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KEYWORDS: Polycross, Microsatellites, Paternity Verification.

Abstract

POLYCROSSES allow different cross combinations among elite parents to be evaluated in a single family. However, the male parent of the progeny is unknown. Microsatellites are considered the marker of choice for fingerprinting and paternity analysis. In this work, the potential of seven microsatellites derived from expressed sequence tags (EST-SSRs) and one genomic (gSSRs) were evaluated to identify the male parent of four sibs selected from one polycross involving nine different male parents. The four sibs were selected based on their high productivity of sugarcane per hectare at plant cane in the year of 2008 at the Sugarcane Breeding Station of Ribeirão Preto, SP, Brazil. The products of the PCR reactions were separated on 6% denaturing polyacrilamide gels and silver stained. The eight SSRs screened over the female parent, the nine male parents and the four selected sibs produced a total of 62 alleles with an average of 7.75 alleles/locus. The genetic similarity (Jaccard coefficient) was calculated among all the materials evaluated. The average genetic similarity among the female parent and the nine male parents (GS = 0.547) was similar to that among the nine male parents (GS = 0.534) and also to that obtained among the four sibs and the nine male parents (GS = 0.539). For each locus, the female parent alleles that were present in each sib were excluded from the analysis to enable us to identify the origin of the male parent alleles present in the sibs. The male parent was identified excluding, for each locus at time, all the female parent alleles that were present in each sib, enabling the identification of the male parent with the alleles present in the sibs. The male parent identified with this approach showed the highest GS with the respective sib in pairwise comparisons among all male parents and sibs. The microsatellites used in the present work were used to successfully identify the male parent of the sibs evaluated.

Introduction

Sugarcane is an allogamous plant vegetatively propagated through stem cuttings. However, sexual reproduction is used by breeders to generate genetic variability for selection through crosses involving two (bi-parental crosses) or more parents (polycrosses).

Although different cross combinations among elite parents can be evaluated in polycrosses in a single family, the male parent of the progeny is unknown.

Nowadays, molecular markers have proven to be an important tool in breeding programs (Eathington, 2007). Among the different types of molecular markers, microsatellites are considered the marker of choice for sugarcane fingerprinting and paternity analysis (Cordeiro, 2001).

In the present study, the potential of seven EST-SSRs and one gSSRs were evaluated to identify the male parent of four sibs selected from one polycross involving nine different male parents genetically related.
Material and methods

Four sibs (clones) derived from one polycross involving the variety IACSP98-6209 (female parent) and nine male parents (SP84-7017, IACSP95-3028, IACSP94-2111, IACSP94-2094, IACSP97-3313, IACSP97-6671, IACSP99-3012, CTC-1, IACSP96-2036) were selected based on their high productivity of sugarcane per hectare at plant cane in the year 2008 at the Sugarcane Breeding Station (Centro de Cana). Seven EST-SSRs (ESTB312, ESTC05, ESTC48, ESTB130, ESTB07, ESTA48) (Oliveira et al., 2009) and one gSSRs (SMC1047HA) were used. These microsatellites were chosen based on the high quality of the amplification products. PCR reactions and separation of the amplified products were performed according to Oliveira et al. (2009). Markers were scored based on their presence/absence and used to estimate the genetic similarity between all the materials evaluated, adopting the Jaccard similarity coefficient using the NTSYS-PC software, version 2.0 (Exeter Software, NY, USA; Rohlf, 1993).

Results and discussion

The eight SSRs screened over the materials produced a total of 62 alleles (markers) ranging from 2 (ESTB130) to 13 (ESTA48) with an average of 7.75 alleles/locus. The pairwise genetic similarity among all the materials was moderate (0.603) and that among the nine candidate male parents (0.534) was slightly inferior to the average value estimated among the female parent and the nine candidate male parents (0.547).

The identification of the most probable male parent was done for each locus at time, excluding all female parent markers present in the sibs (clones) and analysing only the candidate male parent markers (Table 1).

Table 1—Identification of the probable male parent based on the exclusion of the female parent markers.

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<th>Female</th>
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<th>Male 2</th>
<th>Male 3</th>
<th>Male 4</th>
<th>Male 5</th>
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<td>ESTB312.8</td>
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<td>0</td>
<td>1</td>
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<td>1</td>
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<td>ESTC04.8</td>
<td>0</td>
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<td>1</td>
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</tr>
<tr>
<td>ESTB82.2</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
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</tr>
<tr>
<td>SMC1047HA.11</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
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<td>1</td>
<td>0</td>
<td>0</td>
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<td>1</td>
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<tr>
<td>ESTA48.12</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>6</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>6</td>
</tr>
</tbody>
</table>

With this approach, it was possible to assume that the clones 17, 19, 21 and 30 have, as the most probable male parent, the sugarcane varieties IACSP97-3313, IACSP94-2111, IACSP94-2094 and IACSP97-6671 respectively. Indeed, exclusion of female parent markers constitutes a successful strategy in paternity identification (Buteler et al., 1997) being able, in our work, to indicate the most probable male parent.

As shown in Table 1, the male parent of clone 17 was easily identified, as the EST derived markers ESTC05.2 and ESTA48.7 were exclusively from the variety IACSP97-3313. The same was observed for clone 19, for the markers ESTC05.5 and SMC1047HA.5 that were exclusively from the variety IACSP94-2111.

As expected, the most probable male parent identified by the exclusion of the female parent markers approach, showed the highest genetic similarity with the respective clone (Table 2).

Table 2—Pair wise genetic similarity for female parent, clones and candidate male parents estimated based on 62 microsatellite markers.

<table>
<thead>
<tr>
<th>Clone</th>
<th>Female</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
<th>P7</th>
<th>P8</th>
<th>P9</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>0.765</td>
<td>0.512</td>
<td>0.526</td>
<td>0.512</td>
<td>0.579</td>
<td><strong>0.722</strong></td>
<td>0.512</td>
<td>0.475</td>
<td>0.610</td>
<td>0.524</td>
</tr>
<tr>
<td>19</td>
<td>0.649</td>
<td>0.432</td>
<td>0.475</td>
<td><strong>0.610</strong></td>
<td>0.452</td>
<td>0.575</td>
<td>0.465</td>
<td>0.463</td>
<td>0.558</td>
<td>0.548</td>
</tr>
<tr>
<td>30</td>
<td>0.514</td>
<td>0.487</td>
<td>0.500</td>
<td>0.564</td>
<td>0.556</td>
<td>0.487</td>
<td><strong>0.706</strong></td>
<td>0.486</td>
<td>0.590</td>
<td>0.500</td>
</tr>
<tr>
<td>21</td>
<td>0.676</td>
<td>0.595</td>
<td>0.528</td>
<td>0.442</td>
<td><strong>0.727</strong></td>
<td>0.553</td>
<td>0.556</td>
<td>0.566</td>
<td>0.500</td>
<td>0.525</td>
</tr>
</tbody>
</table>


Although the 8 microsatellites used in the present work were able to identify the male parent, other polycrosses are being evaluated with this same set of microsatellites to verify their potential in polycross paternity identification.

REFERENCES


ÉVALUATION DES MARQUEURS MICROSATELLITES FONCTIONNELS
POUR L’ANALYSE DE LA PATERNITÉ DANS
LES POLYCROISEMENTS DE LA CANNE À SUCRE

Par
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MOTS CLÉS: Polycroisements, Microsatellites,
Vérification de Paternité.

Résumé
LES POLYCROISEMENTS permettent les combinaisons de croisements parmi les parents élites pour être évalués comme une seule famille. Cependant, le parent mâle des progénitures est inconnu. Les microsatellites sont considérés comme les marqueurs de choix pour établir l’empreinte génétique pour l’analyse de la paternité. Le potentiel de sept microsatellites dérivés des étiquettes de séquences exprimées (EST-SSRs) et un microsatellite génomique (gSSRs) ont été évalués dans cette étude pour identifier le parent mâle de quatre progénitures. Celles-ci ont été sélectionnées d’un polycroisement impliquant neuf différents parents mâles. Les quatre progénitures ont été choisies en 2008 au Sugarcane Breeding Station de Ribeirão Preto, SP, Brésil sur la base de leur rendement élevé à l’hectare en vierge. Les produits PCR ont été séparés sur gel dénaturant de polyacrilamide de 6% suivi de la coloration au nitrate d’argent. Les huit SSRs criblés par rapport au parent femelle, les neuf parents mâles et les quatre progénitures ont produit au total 62 allèles avec une moyenne de 7.75 allèles/locus. La similarité génétique (coefficient de Jaccard) a été calculée parmi le matériel évalué. La similarité génétique moyenne parmi les parents femelles et les neuf parents mâles (GS = 0.547) était similaire à celles des neuf parents mâles (GS = 0.534) et également à celle obtenue pour les progénitures et les neufs parents mâles (GS = 0.539). Pour chaque locus, les allèles des parents femelles qui étaient présents dans chaque progéniture étaient exclus de l’analyse pour permettre d’identifier l’origine des allèles des parents mâles présents dans les progénitures. Le parent mâle a été identifié en excluant, pour chaque locus, les allèles transmis par le parent femelle et qui étaient présents dans les progénitures, permettant ainsi l’identification du parent mâle. Le parent mâle identifié grâce à cette approche a démontré que le GS est le plus élevé avec sa progéniture respective dans des comparaisons par paires parmi tous les parents masculins et progénitures. Les microsatellites utilisés dans cette étude ont été capables de mener à bien l’identification du parent mâle des progénitures évaluées.
EVALUACIÓN DE LOS MARCADORES FUNCIONALES MICROSATÉLITES PARA ANALISIS DE PATERNIDAD EN POLICRUZAMIENTOS EN CAÑA DE AZÚCAR

Por

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S. CRESTE¹, T.M. FÁVERO¹, M. CAMPANA¹.
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PALABRAS CLAVE: Policruzamientos, Microsatélites, Verificación Paternal.

Resumen

Los policruzamientos permiten diferentes cruzas entre parentales élites para evaluar en familias, aunque el parental masculino es desconocido. Los microsatélites son considerados marcadores útiles para descifrar su identidad genética, así como para el análisis de paternidad. En este trabajo se evalúa el potencial de siete microsatélites derivado de secuencias expresadas (EST-SSRs) y un genómico (gSSRs), para identificar el parental masculino de cuatro hermanos seleccionados de un policruzamiento que tiene nueve padres masculinos diferentes. Los cuatro hermanos fueron seleccionado basándose en su alta productividad de azúcar por ha en caña planta en el 2008, evaluados en la Estación de Mejoramiento de Ribeirão Preto, SP. Brasil. Los productos de la reacción de PCR fueron separados en un gel de poliacrilamida al 6% y luego teñido con plata. Los ocho SSRs identificados en el parental femenino, nueve del parental masculino y cuatro de los hermanos produjeron un total de 62 alelos con un promedio de 7.75 alelos/locus. Se calculó la similaridad genética (Coeficiente de Jaccard) entre los materiales evaluados. El promedio de similaridad genética entre el parental femenino y los nueve masculinos (GC = 0.547), fue similar al de los nueve parentales masculinos (GS = 0.534), así como el obtenido entre los cuatro hermanos y los nueve parentales masculinos (GS = 0.539). Para cada locus, el alelo del parental femenino que estuvo presente en cada hermano se excluyó del análisis para que permita identificar el origen de los alelos del parental masculino presente en los hermanos. El parental masculino se identificó luego de excluir todos los alelos al mismo tiempo del parental femenino presente en cada uno de los hermanos, para permitir la identificación de los alelos del parental masculino en los hermanos. El parental identificado con este sistema mostró el más alto valor de GC relación a su respectivo hermano en comparaciones pareadas entre parentales y hermanos. Por tanto, los microsatélites usados en este trabajo fueron usados en forma efectiva para identificar el parental masculino del grupo de hermanos evaluados.
SELECTING VARIETIES FROM SEEDLING STAGE IN GPS SUGARCANE ESTATES

By
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L. BARAU\textsuperscript{1} and B. AHONDOKPE\textsuperscript{3}

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KEYWORDS: On-Site Selection, Varietal Adaptation, Contrasting Environments.

Abstract

GROUPEMENT DES Professionnels du Sucre (GPS) is an association that groups three sugarcane estates in central Africa (SOSUCAM in Cameroon, CST in Chad, and SARIS in Republic of Congo) owned by the Group SOMDIAA. In order to improve the performance of selection and to face the challenge of renewing the variety situation, CERF and GPS has developed a strong partnership. Previously, the choice of cultivated varieties was based on a ten-year selection scheme supplied every year with 100 foreign varieties (elites and pre-selected varieties). This raises a major problem: the introduced varieties, selected abroad, are not well adapted to specific agro-climatic conditions of GPS estates. Moreover, previous results obtained by CERF showed that on-site selection increases the probability of identifying promising varieties. So it has been decided to establish a selection program for each estate with fuzz imported from CERF. Since 2005, CERF has made specific crosses for each estate and has dispatched the fuzz to the respective estates. About 4000 seedlings are raised in the respective estates and screened through a selection scheme designed by CERF. Training was provided to the estate personnel for raising and managing the seedlings for propagation. Results on family selection at the first stage (seedling nursery) and individual visual selection at ‘stage 2’ are presented for the first four years of this project.

Introduction

Growing high potential yield sugarcane varieties is a key point to increase field productivity. SOMDIAA owns three sugarcane estates in central Africa (SOSUCAM in Cameroon, CST in Chad, and SARIS in Congo). These estates must take up the challenge to develop an efficient method to identify high-yielding sugarcane varieties. In 2005, GPS (the association of the three sugarcane estates) decided, in partnership with CERF (the research centre responsible for sugarcane breeding in Réunion Island), to restructure its selection programs.

Three contrasting environments

SOSUCAM is situated along the Sanaga River, at 120 km north-east from Yaounde.

The subequatorial climate of SOSUCAM is characterised by two dry seasons, from November to March and from mid-June to mid-August (Figure 1). The annual average precipitation is 1450 mm generally well distributed throughout the year except for the dry months. Temperature varies from 23.5°C in July to 26.5°C in February. Humidity is very high and drops below 70% only during the long dry season. Daily evaporation is low: 3.8 mm/day. Sugarcane is cultivated under rainfed conditions.

The deep soil has good available water capacity and drainage is easy. Chemical properties are not so propitious: acid pH and low organic matter (Viremouneix, 2009).
CST is near Banda, near the Chari River, 600 km south east of N’Djamena. The tropical climate of CST is divided in two seasons: the dry season (from November to April) and the wet season (from May to October).

Monthly mean temperature varies from 24.2°C to 31.4°C. The annual average precipitation is 1023 mm; the average evaporation is 5.75 mm per day.

The humidity is relatively low (~45%). Fields are irrigated by pivot irrigation, by drip irrigation, or by gravity.

Depending on the ground water table depth and soil clay content, subsurface drain pipes are necessary. Although pH is 6, the soil has poor organic matter content and reveals a slight deficiency in phosphorus and potassium (Viremouneix, 2009).

SARIS is situated in Niari Valley, 250 km from Brazzaville.

The climatic year is composed of a wet season (from October to May) and a short dry season (from June to September). Monthly mean temperature varies between 23.8°C and 27.5°C. Evapotranspiration is low (~3.9 mm/day) (Viremouneix, 2009).

Soil is rich with a pH of 5.3, with high phosphorus and organic matter content.

Contrasting agronomic results

The contrasting agronomic data (Table 1) can be explained by the contrasting environments and cultural practices, but they could be improved on each sugar estate. Selecting adapted sugarcane varieties is a key point to achieve this objective.

Fig. 1—Monthly rainfall distribution and mean monthly temperature for GPS estates.
Table 1—Agronomic performances of the three sugarcane estates.

<table>
<thead>
<tr>
<th></th>
<th>Area planted (ha)</th>
<th>Cane yield/ha (TC/ha)</th>
<th>Sugar content (%)</th>
<th>Sugar yield/ha (TS/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOSUCAM</td>
<td>20 000</td>
<td>70.5</td>
<td>13.2</td>
<td>7.0</td>
</tr>
<tr>
<td>CST</td>
<td>3872</td>
<td>86.7</td>
<td>13.4</td>
<td>9.2</td>
</tr>
<tr>
<td>SARIS</td>
<td>12 000</td>
<td>58.9</td>
<td>13.31</td>
<td>6.1</td>
</tr>
</tbody>
</table>

The previous selection program and its results

Since 1984, GPS estates were importing around 100 sugarcane varieties per year from different breeding stations such as, WICSCBS (Barbados), SBI (India), CIRAD (Guadeloupe), SASRI (South Africa), and CERF (Reunion).

The imported varieties could be:
1. Elite varieties i.e. they had better agronomic performance than standards in their original country and were adapted to the agro-ecological zones where they were selected.
2. Pre-selected varieties i.e. they had gone through the first selection trials in the respective countries.

To identify the best performing varieties, GPS has developed a ten-year selection scheme for each site (Figure 2). Figures 3, 4 and 5 show variety distribution at SOSUCAM, CST, and SARIS respectively.
SOSUCAM cultivates mainly two varieties: Co 997 and B 46/364 on 97% of the cane area (Figure 3). B82333 and Fr 81/258 are being multiplied.

More than 57% of CST cane area is planted with Co 997, 21% with SP 701284, 12.5% with N12 (Figure 4). The varieties R570 and N18 are promising for commercial exploitation.

Four major varieties are cultivated at SARIS: B 46/364, NCo 376, Co 997 and R570; each cover around 20% of the cane area (Figure 5). N 19 and Mex73523 are under multiplication (Viremouneix, 2009).

Some old varieties are cultivated on most of the estates. Although a significant effort is being made to renew the cultivar situation, GPS selection programs are not reaping the expected results.

**The new selection scheme**

To improve the selection efficiency, GPS requested CERF expertise. The main weakness of the GPS selection program is its over reliance on imported varieties. Selecting in an environment and expecting similar performance in a different environment is a strategic error (Simmonds, 1991; Bouvet et al., 1985).

Site-specific selection potentially generates local adaptation, and enables the identification of specific elites (Simmonds, 1991; Barau, 2007).

Since 2005, the estates have established a selection program from fuzz imported from CERF and supported with CERF expertise.

The goal is to raise 4000 seedlings per year per estate. As it is not possible to accurately predict cross performance, the only way to identify the best families is testing a large number of crosses.

However, the performance of the parent is a good indicator for targeting crosses (Hogarth et al., 1997). So, parent varieties were identified as the ten best cultivars in each estate.
CERF breeders provided training to the estate personnel in Réunion Island and in Chad:

1. to design a new selection scheme
2. to manage seedling germination and propagation
3. to grow and select the seedling nursery
4. to select ‘stage 2’ where each variety is planted on one 3 m-line.

Fuzz is sown in trays under a plastic tunnel. A few weeks after germination, seedlings are potted. Three months later, seedlings are transplanted into the nursery. About four months after transplanting, the nursery is selected using a visual grade assigned to each family, which defines the selection rate per family.

About 30% of the seedlings are selected and planted into stage 2 (3 m plots) for clonal selection. In first ratoon, clones are evaluated for agro-morphological characters at 10 months, and Brix is measured on the clones with the best visual grades.

About 6% of cultivars (72 clones per site) are selected and screened through the ten-year classic selection scheme (Figure 2). Thus, the complete new selection program lasts around 14 years.

### Table 2—Ten best varieties identified on GPS estates.

<table>
<thead>
<tr>
<th>CST</th>
<th>SOSUCAM</th>
<th>SARIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co 997</td>
<td>B 46 364</td>
<td>NCo 310</td>
</tr>
<tr>
<td>N 12</td>
<td>Co 997</td>
<td>NCo 376</td>
</tr>
<tr>
<td>N 14</td>
<td>B 70 532</td>
<td>N 14</td>
</tr>
<tr>
<td>SP 701284</td>
<td>B 51 129</td>
<td>SP 70 1143</td>
</tr>
<tr>
<td>NCo 376</td>
<td>NCo 376</td>
<td>R 570</td>
</tr>
<tr>
<td>N 18</td>
<td>Co 62175</td>
<td>Co 997</td>
</tr>
<tr>
<td>R 579</td>
<td>B81332</td>
<td>N 19</td>
</tr>
<tr>
<td>M 3145</td>
<td>N18</td>
<td>B 46 364</td>
</tr>
<tr>
<td>Co 449</td>
<td>Co 449</td>
<td>Mex 73 523</td>
</tr>
<tr>
<td>Q 75</td>
<td>Co740</td>
<td>SP 71 6180</td>
</tr>
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</table>

### Table 3—Site-specific selection scheme.

<table>
<thead>
<tr>
<th>Year</th>
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<th>2–3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0–3 months</td>
<td>3–10 month</td>
<td></td>
</tr>
<tr>
<td>Selection stage</td>
<td>Hybridisation</td>
<td>Seedlings</td>
<td>Transplantation in the field (nursery)</td>
</tr>
<tr>
<td>Population size (crosses/varieties)</td>
<td>120 crosses</td>
<td>12 000</td>
<td>12 000</td>
</tr>
<tr>
<td>Number of crosses/varieties per site</td>
<td>40 crosses</td>
<td>4000</td>
<td>4000</td>
</tr>
<tr>
<td>Elementary plot</td>
<td>Crossing lanterns</td>
<td>Germination tray</td>
<td>1 seedling per variety</td>
</tr>
<tr>
<td>Selection Site</td>
<td>Réunion Island</td>
<td>Chad Cameroon</td>
<td>Chad Cameroon</td>
</tr>
<tr>
<td>Visual Selection criteria</td>
<td>Choice of parents Listed in Table 2 and CERF elites</td>
<td>Agronomic observation on family</td>
<td>Agronomic observation</td>
</tr>
<tr>
<td>Selection criteria</td>
<td>Brix of the best varieties at 1st ratoon</td>
<td>Selection on ratoon only</td>
<td></td>
</tr>
</tbody>
</table>

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About 6% of cultivars (72 clones per site) are selected and screened through the ten-year classic selection scheme (Figure 2). Thus, the complete new selection program lasts around 14 years.
Table 4—Population of seedlings obtained and number of clones in selection trials at each site.

<table>
<thead>
<tr>
<th></th>
<th>CST</th>
<th>SOSUCAM</th>
<th>CST</th>
<th>SOSUCAM</th>
<th>CST</th>
<th>SOSUCAM</th>
<th>SARIS</th>
<th>CST</th>
<th>SOSUCAM</th>
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<tr>
<td>2005</td>
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<td>36</td>
<td>19</td>
<td>18</td>
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<td>43</td>
<td>25</td>
<td>42</td>
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<tr>
<td>2008</td>
<td></td>
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</tr>
<tr>
<td>No. of Crosses</td>
<td>23</td>
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<td>19</td>
<td>18</td>
<td>32</td>
<td>43</td>
<td>25</td>
<td>42</td>
<td>28</td>
<td>28</td>
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<tr>
<td>No. of seedlings raised</td>
<td>2587</td>
<td>33</td>
<td>2099</td>
<td>2274</td>
<td>10 100</td>
<td>9449</td>
<td>6559</td>
<td>4100</td>
<td>5616</td>
<td>6616</td>
</tr>
<tr>
<td>No. of clones at stage 2 ‘1 row’</td>
<td>768</td>
<td>9</td>
<td>634</td>
<td>745</td>
<td>*</td>
<td>2828</td>
<td>1428</td>
<td>*</td>
<td>1671</td>
<td>*</td>
</tr>
<tr>
<td>No. of clones at stage ‘Pre selection’</td>
<td>91</td>
<td>5</td>
<td>*</td>
<td>*</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
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</tr>
</tbody>
</table>

* Data available in December (2009)

Discussion

GPS emphasises the use of the best varieties in crosses. However, a number of varieties are not available in the CERF germplasm collection. So CERF plans to acquire them from the respective breeding centres. Moreover, the extent of flowering may limit their use in crosses since CERF relies on natural flowering for crossing.

CERF has suggested that GPS increase the number of seedlings raised in order to widen the genetic diversity for the new selection scheme.

In 2009, GPS will establish the first experimental trials as per the new scheme (stage ‘Pre-selection’).

In the process of developing the new selection scheme, GPS is faced with a number of difficulties, such as the reliability of the visual grades and the identification of diseases (with the classical scheme, the diseases were monitored by CIRAD).

Furthermore, the selection would progressively be improved from feedback received from GPS. Data on selection rates would rapidly provide useful information on the best crosses and parents.

REFERENCES


LA SELECTION VARIETALE DEPUIS LE STADE SEEDLING 
DANS LES COMPLEXES SUCRIERS DU GPS

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MOTS-CLES: Sélection sur Site, Adaptation Variétale,
Environnements Contrastés

Résumé

Le GPS (Groupement des Professionnels du Sucre) est l’association qui regroupe les trois complexes sucriers de la SOMDIAA en Afrique centrale (la SOSUCAM au Cameroun, la CST au Tchad et la SARIS en République du Congo). Pour améliorer l’efficacité de la sélection et pour renouveler la situation variétale, le CERF et le GPS ont développé un partenariat étroit. Jusque là, le choix des variétés cultivées se basait sur un schéma de sélection de dix ans. Ce schéma de sélection était alimenté par une centaine de variétés étrangères (des variétés élites ou des variétés pré-sélectionnées). Le problème principal de cette démarche réside dans le fait que les variétés introduites et sélectionnées ailleurs n’étaient pas adaptées aux conditions agroclimatiques spécifiques des complexes du GPS. De plus, des résultats obtenus au CERF montrent que la sélection sur site augmente la probabilité d’identifier des variétés prometteuses. Il a donc été décidé d’établir sur chaque complexe, un schéma de sélection à partir de fuzz importé depuis le CERF. Depuis 2005, le CERF réalise des croisements spécifiques pour chaque complexe, puis expédie le fuzz ainsi produit. Environ 4000 seedlings par an sont obtenus sur chaque site. Ces seedlings subissent alors un schéma de sélection élaboré en collaboration avec le CERF. Le personnel des complexes a pu suivre des formations sur la germination et l’entretien des seedlings. Cette étude présente, pour les quatre premières années de ce projet, les résultats de la sélection familiale au stade 1 (pépinière de seedlings) et les résultats de la sélection massale et visuelle du « stade 2 ». 
SELECCIÓN DE VARIETADES DESDE ESTADO DE PLÁNTULAS
EN LOS ESTADOS CAÑEROS DE GPS

Por

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PALABRAS CLAVES: Selección en Sitio,
Adaptación Varietal, Ambientes Contratantes.

Resumen

GPS ES UNA asociación que agrupa a tres estados Azucareros en África Central (SOSUCAM en Camerón, CST en Chad, y SARIS en la República del Congo) y son propiedad del grupo SOMDIAA. CERF y GPS han desarrollado un acuerdo importante entre ellos, con el fin de mejorar la respuesta de la selección y renovar variedades. Anteriormente, las variedades se escogían basándose en un esquema de selección de 10 años, que se aplicaba cada año usando 100 variedades introducidas (variedades élites y pre-seleccionadas). Esto causa un problema mayor que es la introducción de variedades seleccionadas afuera y no están bien adaptadas a las condiciones agroclimáticas específicas de los estados del grupo GPS. Más aún, resultados previos obtenidos por CERF mostraron que la selección por sitio incrementa la probabilidad de identificar variedades promisorias. Por ello, se ha decidido establecer un programa de selección para cada estado, usando semillas de CERF. Se han realizado cruzas específicas para cada estado en la Isla de Reunion para luego sembrar en cada estado, desde el 2005. Estas siembras incluyen alrededor de 4000 plántulas en cada estado y seleccionadas dentro de un esquema de selección elaborado en colaboración del CERF. Se ha entrenado al personal de cada estado para el cuidado, propagación y manejo de las plántulas. En este trabajo se resume los resultados de los primeros cuatro años del proyecto, sobre la selección familiar en Estado I y selección clonal visual en Estado II.
BIOCONTROL OF CHILO SACCHARIPHAGUS (LEPIDOPTERA: CRAMBIĐAE) A KEY PEST OF SUGARCANE: LESSONS FROM THE PAST AND FUTURE PROSPECTS

By

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KEYWORDS: Sugarcane, Stemborers, Trichogramma chilonis, Mass Production, Field Releases.

Abstract

BIOCONTROL of sugarcane stemborers using Trichogramma releases is a common strategy used in numerous countries, and the efficacy of such releases has been proven in most cases. On Reunion Island, the key stemborer Chilo sacchariphagus and its egg parasitoid Trichogramma chilonis have been the subject of intensive research for 10 years. From the identification of the best candidate for biocontrol to mass production and experimental releases in sugarcane fields, improvement has been constantly made through the years, with successful results. In this paper, we report some of the important outcomes, problems encountered and questions that have arisen during the field experiments (Reunion) and laboratory rearing activities (Reunion and France). Behind promising results from an eco-friendly technology that is used worldwide, one of the current debates that remain is the cost of such biocontrol to the growers. Since 2008, a new research and development project has been conducted to optimise the technology of field releases as well as to increase the efficacy of mass production and storage at cold temperature. To deal with profitability and quality and establishing a new industrial process for Trichogramma production, a partnership has been formed with a French company, BIOTOP, which has extensive experience in biocontrol of the maize stemborer Ostrinia nubilalis in France.

Introduction

Chilo sacchariphagus, a key pest of sugarcane

In many regions, sugarcane is the target of insect pests and some of them are very damaging. On Reunion Island, which is a French department, the two major pests are the white grub, Hoplochelus marginalis (Coleoptera: Scarabaeidae), introduced from Madagascar in the seventies and the spotted stemborer, Chilo sacchariphagus, originally from Java. Control of the white grub by the entomopathogenic fungus, Beauveria brongniartii, has been successful, but the spotted stemborer remains problematic.

In the past few years the problem has been increasing due to adoption of a susceptible variety (R579) which often is less productive than the resistant one, R570. Stalk and internodes bored by larval stages result in productivity loss (tonnes cane per ha) of 30% in case of severe infestations (Goebel et al., 1999). Today, it is estimated that at least 10 000 ha of sugarcane (40% of the overall sugarcane area in Reunion) are at medium or high infestation risk.
Because chemical treatments are generally ineffective, expensive and, at the present, none are registered for use, biological control represents a good option that combines environmental preservation and biodiversity conservation.

Why use *Trichogramma* as a biocontrol agent on sugarcane?

*Trichogramma* spp. (*Hymenoptera: Chalcididae: Trichogrammatidae*) are extremely tiny egg parasitoids widely used on sugarcane and other crops in the world to control moth borers of economic importance. They are characterised by wings covered by hairs layered in radiant lines. Once mass-produced and released, the tiny parasites seek out and destroy eggs of caterpillar pests, such as sugarcane borers, codling moths, cotton bollworms, corn borers, spruce budworms and many others (Hassan, 1993; Li *et al*., 1994). The result is a living, biological ‘insecticide’ that strikes only the target pest with no risk to other natural enemies, human health or the environment.

The interest of these parasitoids in biocontrol is evident because they kill the pest at the most critical stage (the egg) before the damage occurs. In France, there is a good example of the efficacy of *Trichogramma brassicae*, which is currently used to control the European corn borer, *Ostrinia nubilalis*, on 20% of the maize crop area (more than 100 000 hectares) (Frandon and Kabiri, 1999). Futhermore, the low cost of production has encouraged the commercialisation of rearing *Trichogramma*.

10 years of research and continuous improvement of field releases

Results were accumulated during two critical periods: Period 1 (2000 to 2004) when preliminary inventory and experiments were conducted in the field and Period 2 (2005 to the present) which mainly focused on the improvement of the quality of production and *Trichogramma* releases. All research phases were supported by funding through the European Union and the Ministry of Agriculture in France.

The importance of identifying the best *Trichogramma* candidate for field releases

In 2000, a thorough inventory of egg parasitoids on the island showed that only one species was present in sugarcane fields: *Trichogramma chilonis* Ishii. Rather than introducing additional egg parasitoids, it was decided to use the local parasitoid which was probably introduced from Indonesia, as was its host. However, further observations concluded *C. sacchariphagus* egg batches were not sufficiently parasitised by the local species to be an effective control measure (Goebel, 1999; Rochat *et al*., 2001). It was then decided to use inundative releases to increase parasitism.

Before implementing such releases, the first step was to select the best candidate through laboratory experiments. To assess the potential of the parasitoid, the functional response of three *T. chilonis* strains (St. Benoît, St. Joseph, and St. Pierre, corresponding to three different climatic conditions, from humid to dry) was tested with *G. mellonella*, a facticious host, and one strain (St. Benoît) with *C. sacchariphagus* host eggs. The functional response is defined as the relationship between the number of prey consumed by a predator/parasitoid and prey density. The shape of the functional response (type II or III) based on logistic regression, attack coefficients and handling times (Th) led to the conclusion that the behaviour of all three strains with *G. mellonella* host eggs exhibited a type III response (Reay-Jones *et al*., 2006). The St. Benoît *T. chilonis* strain had a significantly shorter estimate of handling time than the St Pierre strain ($P < 0.05$).

In addition, the functional response with *C. sacchariphagus* host eggs was also a type II with the St. Benoît strain. Lastly, more *T. chilonis* wasps from this locality developed from the larger *C. sacchariphagus* host eggs (2.9 per egg) relative to *G. mellonella* (1.1 per egg). From these results, it was decided to use the St. Benoît strain for further evaluations.

*Trichogramma* releases: timing and application rates are essential

The rationale behind our biocontrol project conducted in Reunion was to set up inundative releases in sugarcane fields at the beginning of the crop cycle because it corresponds to the oviposition period of the borer which occurs on 1 to 4 months old cane (Tabone *et al*., 2002;
Tabone and Goebel, 2005). Field experiments started in 2001–02 in two locations, Sainte-Marie (SM: humid area/north east part of the island) and Savannah (SAV: dry area/west part of the island) and it was decided to apply 100 000 \( T. \ chilonis \) per hectare per week, during a 4 month-period.

Two-hundred release points/ha were also set up at this time to ensure a good distribution of the parasitoids. The results from these first experiments showed that releases totalling 16 releases significantly increased the cane yield from 15 to 20% depending on the location. In field releases set up later in 2003 (Table 1), the results showed a financial gain estimated from 600 to 1400 €/ha (Soula \textit{et al.}, 2003; Barreault \textit{et al.}, 2005).

Table 1—Effect of Trichogramma releases on damage levels and stalk mass at harvest at Sainte-Marie & Savannah, Reunion Island (2003, Variety R 579).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>% INB (harvest)</th>
<th>Stalk weight (g)</th>
<th>Cane Yield (Tc/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sites</td>
<td>SM</td>
<td>SAV</td>
</tr>
<tr>
<td>Control</td>
<td>SM</td>
<td>22.3 a</td>
<td>12.4 a</td>
</tr>
<tr>
<td>Treated plots</td>
<td>SM</td>
<td>9.1 a</td>
<td>5.6 a</td>
</tr>
<tr>
<td>CV%</td>
<td></td>
<td>47.1</td>
<td>39.9</td>
</tr>
<tr>
<td>F value</td>
<td></td>
<td>6.42</td>
<td>7.05</td>
</tr>
<tr>
<td>( P )</td>
<td></td>
<td>0.0851</td>
<td>0.0766</td>
</tr>
</tbody>
</table>

SB = Stalks bored; INB = Internodes bored; CV = coefficient of variation. Statistical results are from an ANOVA (SAS Institute). For each variable, the means followed by the same letters (a,b) are not significantly different (\( P > 0.05 \), Student-Newmans-Keuls test).

The efficacy of \( Trichogramma \) releases was again confirmed in a 2005 trial, but it was advised to keep the rate of 100 000 \( Trichogramma/ha \) instead of 80 000 (Table 2).

Table 2—Effect of Trichogramma treatments on damage levels and stalk mass at harvest at Sainte-Marie, Reunion Island (2005, variety R 579).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>%INB (harvest)</th>
<th>Stalk weight (g)</th>
<th>Cane Yield (Tc/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>33.1 a</td>
<td>1.78 a</td>
<td>115</td>
</tr>
<tr>
<td>T 80</td>
<td>30.7 b</td>
<td>2.21 b</td>
<td>132</td>
</tr>
<tr>
<td>T 100</td>
<td>25.4 c</td>
<td>2.43 c</td>
<td>150</td>
</tr>
<tr>
<td>CV%</td>
<td>52.8</td>
<td>32.9</td>
<td></td>
</tr>
<tr>
<td>F Value</td>
<td>40.5</td>
<td>122.64</td>
<td></td>
</tr>
<tr>
<td>( P )</td>
<td>0.0001</td>
<td>0.0001</td>
<td></td>
</tr>
</tbody>
</table>

SB = Stalks bored; INB = Internodes bored; CV = coefficient of variation; T80 = 80 000 Trichogramma per ha. Statistical results are from an ANOVA (SAS Institute). For each variable, the means followed by the same letters (a,b) are not significantly different (\( P > 0.05 \), Student-Newmans-Keuls test).

Between 2007 and 2009, two additional experiments confirmed and validated optimisation and simplification of release methods, particularly the reduction of release points per hectare from 200 to 100 (gain yield of 23%) (Marquier \textit{et al.}, 2008). Furthermore, the experiment in 2007 did not show any difference between 100 and 50 release points. This trial is being confirmed in a new experiment with the following treatments:

- Untreated control (UTC);
- Treatments ‘Reference’ (16 weekly releases of 100 000 \( T. \ chilonis \) per ha with 100 release points per ha for 4 months);
- Treatments ‘Period’ (12 weekly releases at the same rate for 3 months);
- Treatments ‘Optimisation’ (8 fortnightly releases of 200 000 \( T. \ chilonis \) per ha with the density of 50 release points per ha for 4 month).
The data are not fully collected yet, but the low level of infestation observed could hinder us from seeing a significant effect among the treatments. In future experiments, we will continue to reduce the number of releases (the ideal is 5 or 6) while ensuring that the efficacy of borer control will not be compromised.

**Predation by ants: how to manage it?**

On Reunion, the importance of predation of *C. sacchariphagus* eggs by ants (mainly *Pheidole megacephala*, the big-headed ant) has been reported as an essential component of the natural control of this pest (Goebel *et al.*, 1999), but ant predation is better known on other stemborer species (Teran, 1980; Bonhof *et al.*, 1997).

The biocontrol strategy which was successfully implemented for some years takes this predatory action into account which is particularly efficient in 6–12 month old cane fields. Unfortunately, our results tend to show ant predation can have a negative impact on the efficacy of *T. chilonis* releases. Because this predatory ant is small and very active, the parasitised eggs released are often predated, despite the different protection systems tested in the field.

To decrease this negative impact, new dispensers with tiny holes to prevent ants from penetrating and feeding on parasitised eggs are being tested. These dispensers are produced by our private partner, Biotop.

**Initial results on diapause and storage at cold temperature.**

To apply a biocontrol strategy on a wider scale, there is a critical need to decrease the costs of insect production and field releases. Delaying emergence of *Trichogramma* spp. is critical for commercial production, and cold storage has been widely studied and used for this purpose (Voegelé *et al.*, 1986; Pitcher *et al.*, 2002; Ventura-Garcia *et al.*, 2002; Özdö, 2004; Rundle *et al.*, 2004; Tezze and Botto, 2004), including its use on *T. chilonis* (Farid *et al.*, 2001; Shirazi, 2006). The technique has many advantages, including reducing overall costs, optimising the organisation and increasing production capacity. The storage capacity of *Trichogramma* will undoubtedly allow better management of staff and premises devoted to production. Finally, by reducing the number of progenies per year the risk of having a genetic drift is minimised. For the field, the possibility to cold store *Trichogramma* with delayed emergence will also facilitate delivery to farmers and reduce the number of releases.

At the end of 2008, a new research program began to determine optimal conditions (T°, RH, photoperiod, developmental stage) for arresting development by diapause or inducing quiescence of *T. chilonis*. Initial efforts allowed us to store the *T. chilonis* strain from Reunion for 2 months in a state of quiescence without affecting biological performance in the laboratory (Table 3 and Figure 1). The egg numbers per female were not different at 6 and 9 weeks (Student’s *t*-test, *p* > 0.05), but fecundity was significantly higher after 3 weeks of storage at 3°C than the control (Student’s *t*-test, *p* < 0.001) (Figure 1).

However, it is essential to determine if cold storage affects the efficacy of *Trichogramma* in the field, which will be an important step for our project in conjunction with our local partner FDGDON (Fédération Départementale de Défense contre les organismes nuisibles).

**Table 3**—Biological parameters of *T. chilonis* after storage at 3°C for 9 weeks

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
<th>Statistical test vs control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fecundity (Mean number of eggs per female ± S.E)</td>
<td>67 ± 5</td>
<td>ns (Chi-2 test, <em>p</em> &lt; 0.05)</td>
</tr>
<tr>
<td>F1 progeny emergence</td>
<td>87%</td>
<td>ns (Chi-2 test, <em>p</em> &lt; 0.05)</td>
</tr>
<tr>
<td>Sex-ratio (% females)</td>
<td>80%</td>
<td>ns (ANOVA, <em>p</em> &gt; 0.05)</td>
</tr>
<tr>
<td>Mortality at 7 days</td>
<td>6%</td>
<td>ns (ANOVA, <em>p</em> &gt; 0.05)</td>
</tr>
<tr>
<td>F2 progeny emergence</td>
<td>82%</td>
<td>ns (ANOVA, <em>p</em> &gt; 0.05)</td>
</tr>
</tbody>
</table>
Fig. 1—Fecundity of T. chilonis after storage at 3°C and 70 – 80% RH for 7 days (sample used for the Control, n = 32 females; 3 weeks, n = 34; 6 weeks, n = 32; 9 weeks, n = 32).

**Trichogramma production: How to optimise biocontrol and the supply?**

The production of T. chilonis has improved through the years by our main partner FDGDON on Réunion. From 2000 to 2004, a small production unit was first set up for experimental needs using the greater wax moth *Galleria mellonella* (Lepidoptera, Pyralidae) as host.

In 2008, FDGDON reached its capacity in production of *G. mellonella* with 8 million eggs and 2 million of *T. chilonis* produced per month. This production is very costly and time consuming and the parasitism level on *Galleria* eggs is often variable.

In 2009, *Galleria mellonella* (Gm) was replaced by the Mediterranean flour moth *Ephestia kuehniella* (Ek), a widely used host for commercial production of *Trichogramma* spp. Further laboratory tests comparing the quality of *T. chilonis* produced on these two factitious hosts concluded that *E. kuehniella* was superior in terms of fecundity per *T. chilonis* female (Ek: 31 parasitised eggs; Gm: 26) average parasitism (Ek: 70%; Gm: 30%) and emergence rate (Ek: 92%; Gm: 55%).

However, rather than starting a new production site locally with FDGDON, we began to produce *Trichogramma* in France via our industrial partner Biotop. In 2009, experiments were conducted from consignments (cool boxes) sent to FDGDON, in Réunion on a regular basis.

The *E. kuehniella* eggs were then conditioned in appropriate dispensers and released in the fields. Having a company specialised in biological control in the project has become a necessity to apply *Trichogramma* releases on a wider scale.

This will also guarantee the quality of production and field releases of beneficial insects at an affordable price to farmers.

Biotop, a company based in France and is a subsidiary of the InVivo group, plans to develop the appropriate technology for Réunion through our project. Biotop has been working many years on improving the use of *Trichogramma brassicae* to control the European corn borer, *Ostrinia nubilalis*.

After 20 years of experience, this strategy is used in France on 120 000 ha of maize (2008); good results have convinced many farmers to adopt biological control instead of chemical control.

Biotop has successfully developed a technology based on very efficient preparation and packaging plus delayed emergence of *Trichogramma* in the fields (Figure 2). The parasitised eggs are prepared in special dispensers, made with cardboard sheets, which protect eggs from predators and rain or irrigation during several weeks.

These preparations use different stages of *T. chilonis* larvae (basically 4 stages) in order to successively release waves of this parasitoid, providing a long duration of beneficial activity. It has been possible to reduce the number of applications in corn fields from three to only one, with the same efficacy. In addition, the dispensers are easily supported by the plants and it is possible to treat 5 ha in one hour walking in the fields.

![Figure 2](image-url) — An example of the ultra-delayed release waves in dispensers implemented by Biotop for the control of the European corn borer *O. nubilalis* in France

In France, the cost of a *Trichogramma* application approximates a chemical application, including the mechanisation, of about 35€/ha. For this project, the goal is to use the same release technology with an expectation of controlling the pest with six applications, at a cost to the farmer ≈ 200€/ha. Considering the financial gain due to biological control, this price is affordable for sugarcane farmers.

**Discussion: which biocontrol strategy for the sugarcane industry in the future?**

Based on the promising results obtained and the experience accumulated during this project, we are confident that biocontrol using *Trichogramma* spp. will be a success story and a realistic strategy for growers to reduce borer infestations. However, *Trichogramma* is just one of the components of biocontrol and certainly not a panacea. From our experience in Reunion, we have learned that a biocontrol program needs proper research following strict protocols and requires constant technical improvement. The failure of borer control using *Trichogramma* spp. in the 1960s and 1970s was partly due to lack of research on parasitoids themselves (species, bionomics and efficacy), but also lack of quality control of mass production (Goebel, 1999). During this period, biological programs often introduced exotic parasites and released them without evaluating (in some cases) their impact on pests (Goebel, 1999). All these facts have led to a negative image of biocontrol with *Trichogramma* spp. and other parasitoids and loss of interest for this strategy (Tabone et al., 2002). Nevertheless, many countries, such as Indonesia (Java) and India are using this parasitoid as the main component of their biocontrol strategy. Indonesia is still producing millions of *Trichogramma* in association with the sugar factories while India has seen small farmers taking over the production and release of *Trichogramma* wasps in their own fields.

Another example is Brazil which has succeeded in controlling *Diatraea saccharalis* using two parasitoids: *Cotesia flavipes* and *Trichogramma galloi* (Botelho et al., 1999). This example is noteworthy as it is an example where key parasitoids are used in concert. It demonstrates that it is preferred to have additional pressure on stemborer populations. It is an interesting option to
consider for Reunion. As we have seen, predation should also be considered as a component of the system.

Research and Development activities should continue to improve biocontrol in all its components: quality control, cost reduction, conditioning, packaging, efficacy and adoption by growers. We have started to understand the induction mechanisms of quiescence and/or diapause of *T. chilonis* in laboratory conditions. If successful, this research offers the possibility of storing the parasitoid for long periods without loss of viability.

In the era of GMOs and the concern of the environmental impacts of such technologies, biological control remains a credible alternative for ecologically, sound-based pest management.

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CONTROLE BIOLOGIQUE CHILO SACCHARIPHAGUS (LEPIDOPTERA: CRAMBIDAE) UN RAVAGEUR CLE DE LA CANNE A SUCRE: LEÇONS DU PASSÉ ET PROSPECTIVE FUTURE

Par

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MOTS-CLES: Canne à Sucre, Foreur des Tiges, Trichogramma chilonis, Production de Masse, Lâchers au Champ.

Résumé

Le contrôle biologique des foreurs de la canne à sucre utilisant les lâchers de \textit{Trichogramma} est une stratégie commune utilisée dans de nombreux pays et l’efficacité de tel lâcher a été prouvée dans la plupart des cas. À l’île de la Réunion, un ravageur-clé \textit{Chilo sacchariphagus} et son parasitoïdes d’œufs \textit{Trichogramma chilonis} ont été le sujet d’une recherche intensive depuis 10 ans. De l’identification d’un meilleur candidat pour le contrôle biologique à la production de masse en passant par les lâchers expérimentaux dans les champs de canne à sucre, des améliorations ont été constamment apportées au fil des années, avec succès. Dans cet article, nous présentons des avancées majeures de cette recherche, les problèmes rencontrés et les questions qui ont été soulevées au cours des expérimentations au champ (Réunion) et lors des activités d’élevage au laboratoire (Réunion et France métropolitaine). Derrière les résultats prometteurs d’une technologie qui préserve l’environnement et utilisée à travers le monde, l’un des débats actuels qui demeure est le coût d’un tel contrôle biologique pour les planteurs. Depuis 2008, un nouveau projet de recherche-développement est conduit pour optimiser la technologie des lâchers au champ et accroître l’efficacité de la production de masse et du stockage au froid. Pour répondre aux critères de rentabilité et de qualité avec mis en œuvre d’un nouveau process industriel pour la production de \textit{Trichogramma}, un partenariat a été créé avec la société française BIOTOP qui a une expérience large et reconnue sur la lutte biologique contre le foreur du maïs \textit{Ostrinia nubilalis} en France.
CONTROL BIOLÓGICO DE CHILO SACCHARIPHAGUS (LEPIDOPTERA: CRAMBIIDAE) UNA PLAGA CLAVE DE LA CAÑA DE AZÚCAR: LECCIONES DEL PASADO Y PROSPECTOS DEL FUTURO

Por

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Palabras clave: Caña De Azúcar, Barrenadores, Trichogramma Chilonis, Producción Masiva, Liberaciones en Campo

Resumen
EL CONTROL biológico de barrenadores de la caña de azúcar usando liberaciones de Trichogramma es una estrategia común usada en muchos países, y la eficacia de estas liberaciones ha sido probada en la mayoría de los casos. En la Isla Reunión, el principal barrenador Chilo sacchariphagus y su parasitoide de huevos Trichogramma chilonis han sido objeto de investigación intensiva durante 10 años. Se han hecho mejoras constantemente a través de los años con resultados exitosos desde la identificación del mejor agente de control biológico, su producción masiva y experimentos de liberaciones en campo. En este trabajo, se informa sobre algunos de los resultados importantes, los problemas encontrados y las preguntas que surgen durante los experimentos de campo (Reunión) y las actividades de cría en laboratorio (Reunión y Francia). Detrás de los resultados prometedores de una tecnología eco-amiga que se utilice a nivel mundial, uno de los debates actuales que permanecen es el costo de estos controladores biológicos para los cultivadores. Desde 2008, una nueva investigación y proyecto de desarrollo se está conduciendo para optimizar la tecnología de liberaciones de campo así como para aumentar la eficacia de la producción masiva y almacenamiento en frío. Para tratar sobre la viabilidad económica y calidad, se está estableciendo un nuevo proceso industrial para la producción de Trichogramma, se ha formado una sociedad con una compañía francesa, BIOTOP, la cual tiene una larga experiencia en control biológico del barrenador del maíz Ostrinia nubilalis en Francia.
THE EFFECT OF BAGASSE FURNACE ASH APPLICATION ON SUGARCANE RESISTANCE TO TOP BORER SCIRPOPHAGA NIVELLA INTACTA SNELLEN (LEPIDOPTERA: PYRALIDAE)

By

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KEYWORDS: Sugarcane, Bagasse Furnace Ash, Top Borer, Resistance, Silicon.

Abstract

SUGARCANE top borer, Scirpophaga nivella intacta Snellen, is a major pest of sugarcane at PT Gunung Madu Plantations, Lampung, Indonesia. Infestation on several commercial varieties is alarming despite an integrated control program. Many studies have been done in South Africa, Hawaii, Florida, India, and Taiwan on use of the element silicon to improve plant resistance to pest and disease. Bagasse furnace ash, plentiful at a cane sugar factory, is known as an important silicon source. A field trial was conducted in the plantation to study the effect of bagasse furnace ash application on sugarcane resistance to top borer infestation. A susceptible variety TC4 was used. Treatments comprised a control and 40, 80, and 120 t/ha of pre-plant broadcast application. In the 120 t/ha treatment, the number of top borer larvae successfully boring into the leaf spindle was 20.7% fewer than the control. Also 19.2% fewer larvae bored into the growing point and the internodes. Similarly, the length of boring tunnels (measured from the growing point) in this treatment was shorter than in the control. In addition, stalk population, height, and diameter increased with the rate of ash application. Application of 120 t/ha bagasse furnace ash of approximately 7.97 ± 0.58% silicon content increased the resistance of susceptible variety TC4 to top borer infestation and increased the cane yield by 39.89%.

Introduction

Sugarcane moth borers (Lepidoptera: Pyralidae) are predominant pests in Gunung Madu sugarcane plantation, Lampung, Indonesia. The borer complex consists of white top borer (Scirpophaga nivella intacta Snellen), and spotted- and glossy- stem borers (Chilo sacchariphagus Boj. and C. auricilius Dudg.). Borer population cycles overlap under the tropical conditions found here. Infestation pressure is exacerbated by the massive size of the plantation (> 25 000 ha) and uninterrupted mono-cropping practices applied therein (Sunaryo, 2005).

Stem borers have been acceptably controlled by augmented natural enemies reared in the laboratory such as egg parasitoid Trichogramma chilonis Ishii and larval parasitoids Cotesia flavipes Cam. and Sturmiopsis inferens Tns.

Top borers have been acceptably controlled by recolonisation and preservation of natural enemies in the field and soil application of granular insecticide on selective fields of young canes adjacent to heavily damaged mature canes. At the peaks of moth flight, a combination of light trappings and manual collection has been occasionally done to reduce moth populations. However, the overall infestation in the last decade reached 7.80% (3.04 – 13.52%) and was 9.61% (3.47 – 18.77%) on susceptible variety TC4. Other approaches are explored to improve the overall result.
Top borers lay eggs on the uppermost leaves; the hatched larvae then penetrate the leaf spindle through the midrib. They move to the growing point, kill it and bore further downward into the internodes. They feed and transform into pupae inside the internodes.

Field and greenhouse trials in Florida, Hawaii, and Mauritius indicated that the application of silicon fertiliser had a positive effect on sugarcane resistance to pests, diseases, and frost tolerance (Matichenkov and Calvert, 2002). This knowledge is potentially useful, as silicon is concentrated in bagasse ash (furnace- and fly-ash), which is abundantly available at most sugar mills. In India, sugarcane varieties which are resistant to shoot borer were found to contain higher silicon per leaf area unit, and a study in Taiwan showed that borer infestation on silicon-treated sugarcane was lower compared with untreated cane (Meyer and Keeping, 2005). Keeping and Meyer (2006) compared the efficacy of several silicon sources, including fly ash, on controlling boring by *Eldana*. Also from South Africa, Kvedaras *et al.* (2007) reported a comprehensive study on soil applied silicon, sugarcane cultivars, and borer feeding sites in the stalks.

The objective of the present study is to find out the effect of the application of bagasse furnace ash on sugarcane resistance to top borer *S. nivella intacta*. This material is abundantly available at most sugar mills. The use of bagasse to fuel mill boilers at Gunung Madu sugar mill (12 000 TCD) leaves up to 23 000 t bagasse furnace ash annually, and therefore it is potentially a good and practical silicon source for this purpose.

**Materials and method**

The present study was carried out at Gunung Madu sugarcane plantation, Lampung, Indonesia (approximately 4°42’ S/105°12’ E), from August 2005 to July 2006. The study used field plots 20 m long x 40 m (26 sugarcane rows) wide, with 5 m inter-plot spacing. In each plot, 16 rows were selected for pest observation and 10 other rows for agronomy observation.

The treatments consisted of one control (no-ash application) and 40, 80, and 120 t/ha-of bagasse ash application, each replicated three times in a complete randomised design. The bagasse ash, supplied from Gunung Madu sugar mill, was pre-plant broadcasted as in Keeping *et al.* (2004). Silicon content of the material, analysed at the Soil and Plant Analysis Laboratory of the plantation using a yellow silico-molybdic acid method, was 7.97 ± 0.58%. TC4 variety, which is highly productive but susceptible to top borer, was planted.

Resistance was assessed on artificially-infested plants. Three newly hatched top borer larvae were laid on top of leaf number –1 of each of 80 sugarcane stalks in each plot. This was done on 9 month old plants, the same plant age chosen by Kvedaras *et al.* (2005). These stalks were marked for spindle and internode observations. Observations were made 14 and 27 days after infestation with 40 infested plants for each observation (where at least one larva was already in the midrib). The first observation was to assess larval penetration and position in the leaf spindle while the second was to assess the extent of boring into internodes.

Infestation success rate in the spindle and internodes was used to describe plant resistance. An infestation was considered successful when the larva was still alive. The distance of larvae from the growing point when they were in the spindle (14 days after infestation) and when they were in the internodes (27 days after infestation) was measured to find out the movement and position of larvae.

The larval infestation success rate (%) within both spindle and internodes was calculated by the number of successful infestations relative to the total samples artificially infested. The infestation success rate (%) in the spindle was formulated as:

\[
\text{infestation success rate in the spindle} = \frac{s}{40} \times 100
\]

where \( s = \) number of successful infestations in the spindle,

40 = total samples infested.
As for larva success rate in the internodes, the following formula was used:

\[(i/40) \times 100\]

where \(i\) = number of successful infestations in internodes,

\(40\) = total samples infested.

Data on stalk population, height, and diameter of millable stalks from 10 through 12 month age (harvest time) were also recorded to give a general idea on the effect of bagasse ash application on cane agronomy. Samples for agronomic evaluations were collected from the specifically assigned 10 rows as described before, ignoring natural top borer infestation that might have occurred therein. In each plot, a row sample equal to 1/1000 ha was used for population counts, out of which 20 stalks were randomly selected for height and diameter measurement. Adequate size of sub-plots were sampled and weighed to estimate cane yield per hectare.

**Results and discussion**

**Larva penetration in leaf spindle (14th day after infestation)**

There was significantly lower initial success rate of infestation in the control compared to the treatment with 120 t/ha ash application, with a reduction (compared to control) of 20.7%. Treatments with 80 and 40 t/ha ash application reduced the success rate by 15.0 and 3.9% respectively (Table 1). The lower success rate of larval penetration into the spindle with higher rate of ash application may be attributed to the increased silicon supply to the plant. The same table shows that larvae were closest to the growing point in the controls and significantly further away in the 80 and 120 t/ha ash treatments. It suggests that the movement of larvae to the growing point was significantly hindered with 80 and 120 t/ha ash applications which presumably contributed to plant resistance.

**Table 1**—Infestation success rate and distance of top borer larvae from growing point in the spindle.

<table>
<thead>
<tr>
<th>Treatment (t/ha)</th>
<th>Infestation success rate (%)</th>
<th>Distance (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>83.7 a*</td>
<td>2.9 c</td>
</tr>
<tr>
<td>40</td>
<td>79.8 ab</td>
<td>3.3 ab</td>
</tr>
<tr>
<td>80</td>
<td>68.7 ab</td>
<td>4.3 bc</td>
</tr>
<tr>
<td>120</td>
<td>63.0 b</td>
<td>4.9 c</td>
</tr>
</tbody>
</table>

* means within the same column followed by the same letter are not significantly different (P = 0.05, HSD- test).

**Larva boring in the internodes (27th day after infestation)**

The application of bagasse furnace ash decreased the infestation success rate into top internodes, similar to the increase of application rate. The 120 t/ha treatment gave the lowest success rate (58.0%) with a tunnel length (treatment average) of 4.1 cm. It means that only 58.0% larvae were found alive and arriving at the growing point or further through the internodes.

Some of the larvae were just at the growing point and 1st internodes (each 10.0%), the remainder have been further down in the lower internodes, but none at 4th internodes. In controls, the success rate was 77.2%, significantly higher by 19.2% compared to 120 t/ha treatment and all larvae have bored further down to 2nd and lower internodes with a total 83.3% at 3rd and 4th internodes (Table 2).

These findings suggest that ash application resulted in lower infestation success rate and may constitute plant resistance. With the increasing rate of ash application, the hindrance to larval movement was greater as indicated by the shorter tunnel length and larval position. It confirms the earlier observation taken on the 14th day.
Table 2—Infestation success rate, tunnel length and larva position in the internodes.

<table>
<thead>
<tr>
<th>Treatment (t/ha)</th>
<th>Infestation success rate (%)</th>
<th>Tunnel length (cm)</th>
<th>Larva position (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Growing point</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; Internode</td>
</tr>
<tr>
<td>0</td>
<td>77.2 a*</td>
<td>5.7 a</td>
<td>0.0 a**</td>
</tr>
<tr>
<td>40</td>
<td>69.8 ab</td>
<td>5.3 ab</td>
<td>0.0 a</td>
</tr>
<tr>
<td>80</td>
<td>64.3 ab</td>
<td>4.3 bc</td>
<td>6.7 a</td>
</tr>
<tr>
<td>120</td>
<td>58.0 b</td>
<td>4.1 c</td>
<td>10.0 a</td>
</tr>
</tbody>
</table>

* means within the same column followed by the same letter are not significantly different (P = 0.05, HSD- test).
** means within the same row followed by the same letter are not significantly different (P = 0.05, HSD- test).

Deposition of silicon in surface cell layers, and especially the epidermis, has a bearing as well on physical surface properties (Epstein, 1999). Pan et al. (1979), using similar bagasse furnace ash as silicon provider, also found that borer damage was lower when compared to no-ash application. The increased presence of silicon crystals in sugarcane plant tissues hinders the feeding of the larvae, which at their early instar has rather fragile mandibles (Meyer and Keeping 2005).

On a different crop, Ukwungwu and Odebiyi (1985) found that silicon increases hardness of plant tissue, interferes with insect larval boring and feeding activity, and constitutes a strong factor in resistance to rice striped borer.

The present results conform to those of Keeping et al. (2004), who assessed the effect on Eldana borer of fly-ash application containing 10% silicon. They reported a similar reduction of borer infestation from 45 per 100 stalks in control plots to 18 per 100 stalks in ash treated plots. Further, Keeping et al. (2008) stated that silicon is accumulated in the epidermis tissues of sugarcane internodes, root bands, and also contained in the internal tissues.

This silicon accumulation obstructs the penetration and larval feeding of Eldana borer, and adversely affects the feeding mechanism. As a result of their slower movement, there will be more time for larvae to be exposed to natural predators, weather stress, or pest control measures (Kvedaras et al., 2008).

The application of silicon fertilisers (based on various silicon sources) has been considered as worth including in the integrated pest management scheme as they do not leave unwanted residues in the sugarcane products and environment, and yet are compatible with any other pest control technique including biological control (Pan et al., 1979).

**Cane agronomy**

Bagasse furnace ash application gave a positive effect on sugarcane stalk population. Stalk population at 10-month age with 120 t/ha ash application was 97 000/ha as compared to 85 000/ha of no-ash application. Statistical analysis showed a significant difference between no-ash application with either 80 or 120 t/ha ash application treatment, where the latter two had higher stalk population (Table 3).

There was also a significant difference on the height of millable stalks between the control and the 120 t/ha ash application treatment, the latter being 13.7 cm longer at 10-month age. Similar effect was observed on stalk diameter, which was only 2.3 cm for no-ash but 3.0 cm for 120 t/ha ash application treatment.

Eventually, at harvest time (12-month age), the total sampled stalks weight was higher on all ash application treatments. The estimated yield with 120 t/ha ash application was 39.9% higher compared to no-ash treatment (Table 3).
Table 3—Population, height, stalk diameter and cane yield.

<table>
<thead>
<tr>
<th>Treatment (t/ha)</th>
<th>Population (x 1000)</th>
<th>Height (cm)</th>
<th>Stalk diameter (cm)</th>
<th>Cane yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>85.8 a*</td>
<td>316.9 ab</td>
<td>2.3 ns**</td>
<td>82.9 a</td>
</tr>
<tr>
<td>40</td>
<td>86.3 a</td>
<td>304.4 a</td>
<td>2.4 ns</td>
<td>88.7 a</td>
</tr>
<tr>
<td>80</td>
<td>95.9 b</td>
<td>330.1 b</td>
<td>2.5 ns</td>
<td>104.5 b</td>
</tr>
<tr>
<td>120</td>
<td>97.0 b</td>
<td>330.6 b</td>
<td>3.0 ns</td>
<td>116.0 b</td>
</tr>
</tbody>
</table>

* means within the same column followed by the same letter are not significantly different (P= 0.05, HSD- test).
** ns = Non-significant.

It appears that, in addition to the potential benefit of improved plant resistance and possible lower borer damage, the ash application under local soil condition, especially at higher rates, has increased stalk population, stalk length and diameter, and eventually the cane yield. This could be due to improved status of silicon in the plant. Elawad (1982), Alloerung (1989), and Matichenkov and Calvert (2002), using various silicon materials, reported a similar cane yield improvement.

Although no biochemical role for Si in the development of plants has been positively identified, it has been proposed that enzyme-Si complexes form in sugarcane that act as protectors or regulators of photosynthesis and enzyme activity. Si can suppress the activity of invertase in sugarcane, resulting in greater sucrose production. A reduction in phosphatase activity is believed to provide a greater supply of essential high-energy precursors needed for optimum cane growth and sugar production. Si additions have improved the growth of sugarcane in Florida, Hawaii, Mauritius, Puerto Rico, and Saipan (Tisdale et al., 1993).

Conclusion

Under the conditions of this trial, the application of bagasse furnace ash has resulted in improved resistance of a susceptible variety to top borer infestation. The ash application at 120 t/ha has significantly lowered the success rate of larval penetration into the leaf spindle and hindered further penetration into the growing point and top internodes. On top of the potential benefit of plant resistance and reducing borer damage, the ash application had the positive effect of improving stalk population, plant height (length), and stalk diameter, which resulted in 39.9% increase in cane yield.

Future studies need to include measurement of silicon content in plant tissues, probably in the midribs, spindle leaves, and the meristem tissues of growing points and top internodes. This is to know the extent of hindrance that silicon may be responsible for the penetration of the top borer. Growth observations, such as periodical plant height measurement, may be worthwhile to learn if there is any improved growth rate due to silicon application that may eventually be responsible for changes in top borer penetration. Also, measurement of larva and pupa weight will be useful to confirm the role of silicon in constituting plant resistance.

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REFERENCES


EFFET DE CENDRE DE BAGASSE SUR LA RÉSISTANCE DE LA CANNE À SUCRE CONTRE LE FOREUR APICAL DE LA CANNE SCIRPOPHAGA NIVELLA INTACTA SNELLEN (LEPIDOPTERA: PYRALIDAE)

Par

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MOTS-CLÉS: Canne à sucre, Cendre de Bagasse, Foreur Apical de la Canne à Sucre, Résistance, Silice.

Résumé

Le foreur apical de la canne à sucre, Scirpophaga nivella intacta Snellen, est un ravageur majeur de la canne à sucre au PT Gunung Madu Plantations, Lampung, Indonésie. L’infestation de plusieurs variétés industrielles est alarmante malgré un programme de lutte intégrée. Plusieurs études en Afrique du Sud, Hawaï, Floride, Inde et Taiwan ont démontré que l’utilisation de la silice peut améliorer la résistance de la plante contre les ravageurs et les maladies. La cendre de bagasse, produit en abondance aux sucreries, est connue pour être une source importante de silice. Un essai a été effectué à la propriété susmentionnée pour déterminer l’effet de la cendre de bagasse sur la résistance de la variété TC4, qui est sensible au foreur. L’essai comprenait un témoin non-traité ainsi que des traitements de 40, de 80, et de 120 t/ha, de cendre appliqués à la volée avant la plantation. Pour le traitement de 120 t/ha, le pourcentage de la feuille du fuseau attaqué était de 20.7% de moins que le témoin. De plus, 19.2% moins de larves ont pénétré le point de croissance et les entrenœuds. La longueur des tunnels forés (mesurée du point de croissance) était aussi réduite pour ce traitement que le témoin. De plus, il a été constaté que le nombre, la longueur et le diamètre des tiges étaient supérieurs en fonction de l’augmentation du taux d’application de cendre. Il a été conclu qu’une application de 120 t/ha de cendre de bagasse avec un taux approximatif de 7.97 ± 0.58% de silice augmente la résistance de la variété TC4 au foreur et occasionne un rendement de canne supérieur par 39.89%.
EL EFECTO DE LA APLICACIÓN DE CENIZAS DE BAGAZO EN LA RESISTENCIA DE LA CAÑA AL BARRENADOR DEL COGOLLO SCIRPOPHAGA NIVELA INTACTA SNELLEN (LEPIDOPTERA: PYRALIDAE)

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PALABRAS CLAVE: Cenizas de Bagazo de Caña, Barrenador del Cogollo, Resistencia, Silicio.

Resumen

EL BARRENADOR del cogollo, Scirophaga nivella intacta Snellen, es una plaga importante de la caña de azúcar en las plantaciones de PT Gunung Madu, Lampung, Indonesia. La infestación en diferentes variedades comerciales es alarmante, pese a que se tiene un programa de control integral. Muchos estudios se han realizado en Sudáfrica, Hawái, Florida, la India y Taiwán sobre el uso del elemento silicio para mejorar la resistencia de las plantas a las plagas y enfermedades. Las cenizas de bagazo, abundante en las fábricas de azúcar, son conocidas como una fuente importante del silicio. Por tanto, se realizó un ensayo de campo en una plantación de caña de azúcar tendiente a estudiar el efecto de las cenizas de bagazo sobre la resistencia de la caña a la infestación por el barrenador del cogollo. La variedad TC4 susceptible fue utilizada. Los tratamientos comprendieron un control y aplicaciones en el campo de 40, 80 y 120 t/ha antes de la siembra. En el tratamiento de 120 t/ha, el número de larvas del barrenador del cogollo emergidas fue de 20.7% inferiores al control. También el número de larvas fue inferior al 19.2% entre el punto de crecimiento y los entrenudos. Del mismo modo, la longitud de los túneles del barrenador (medidos desde el punto de crecimiento) en este tratamiento fueron más cortos que en el control. Además, la población de tallos, altura y diámetros fueron mayor en este tratamiento. La aplicación de 120 t/ha cenizas de bagazo con aproximadamente 7.97 ± 0.58% de silicio aumentó la resistencia de la variedad susceptible TC4 a la infestación del barrenador del cogollo y el aumento de los rendimientos de caña en 39.89%.
UTILISATION OF THE GREEN MUSCARDINE, *METARHIZIUM ANISOPLIAE*, TO CONTROL THE SUGARCANE LONGHORN STEM BORER *DORYSTHENES BUQUETI GUERIN* (COLEOPTERA: CERAMBYCIDAE)

By

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KEYWORDS: Biological Control, *Metarhizium anisopliae*, Entomopathogen, Sugarcane Longhorn Stem Borer.

Abstract

The green muscardine, *Metarhizium anisopliae* is used to control the sugarcane longhorn stem borer, *Dorysthenes buqueti*, in infested areas of sugarcane fields in Thailand. Fields are treated by dispersing a fresh culture of *M. anisopliae* colonising cooked rice \((2.7\times10^8\) spores/g). Single applications of *M. anisopliae* at the rate of 80 kg/ha were made in three locations at Suphanburi and Kanchanaburi Province in 2008. The effect of green muscardine on the larvae of longhorn borer as well as on sugarcane production was evaluated. The results revealed that, after applying the fungi, the green muscardine killed on average 35.09\(\pm\)8.68\% of the borer larvae in all treated plots and 4.49\(\pm\)1.64\% in all non-treated plots. The highest average percent of infested larvae was 41.67\(\pm\)36.03\% at Rang Sa Ri district, Kanchanaburi Province. The sugarcane production averaged 135.61\(\pm\)4.67 t/ha in treated plots while, in non-treated plots, yields averaged 72.11\(\pm\)10.51 t/ha. These findings indicate that the *M. anisopliae* was an effective biological control agent in controlling sugarcane longhorn stem borer in Thailand.

Introduction

The sugarcane longhorn stem borer, *Dorysthenes buqueti* (Coleoptera: Cerambycidae), is considered as one of the most serious insect pests of sugarcane in many areas of sugarcane production in Thailand (Charernsom and Suasaard, 1994). Infestations frequently cause economic losses. In 1998, in some areas of the North-Eastern and the Eastern region, 100\% of the sugarcane fields surveyed were infested by *D. buqueti*. Outbreaks have now spread to all sugarcane growing areas including the lower Northern and the Central regions of Thailand. Sommartya et al. (2007) reported that all entomopathogenic fungi infecting *D. buqueti* larvae collected from sugarcane fields throughout Thailand were identified as *Metarhizium anisopliae* var. *anisopliae*, Family Monilaceae, Order Moniliales, and Class Deuteromycetes. *M. anisopliae* is considered the most effective natural enemy to control *D. buqueti*. It infects all stages of *D. buqueti* killing 100\% of infected larvae in the laboratory 14 days after inoculation with a suspension of 1x10\(^7\) conidia per mL. In the greenhouse, 80–100\% of larvae were killed within 20 days after application. Attempts to utilise *M. anisopliae* as a biological control agent for controlling insect pests was first recorded in 1879 (Cloy, 1999) and is utilised in the field in many countries such as Trinidad, Grenada, Mexico, Guatemala and Canada (Cloy, 1999; Hernandez-Velazquez et al., 2003; Kabaluk and Ericsson, 2007).

The objective of this study was to evaluate the utilisation of *M. anisopliae* var. *anisopliae* as a biological control agent of sugarcane longhorn stem borer, *D. buqueti* under field conditions in Thailand.
Materials and methods

**Mass production of *M. anisopliae***

*D. buqueti* infected larvae were collected from sugarcane fields from several locations and the pathogen was isolated and identified. A pure culture of *M. anisopliae* was used for initial stock culture. Mass production of *M. anisopliae* was carried out by colonisation of cooked rice at the National Biological Control Research Center (NBCRC) Central Regional Center, Kamphaeng Saen, Nakhon Pathom.

About 3000 kg of fresh culture on cooked rice were produced monthly for application and evaluation in the fields.

**Field application and assessment**

Three test sites each were established in the Rang Ngoen, Pho Ngoen, Suphanburi Province and Rang Sa Ri Districts of Kanchanaburi Province in the central region of Thailand. *D. buqueti* is a serious pest in these areas.

At each site, 2 plots (ca.10 ha) were selected for treated and non-treated (control) *M. anisopliae* plots. Approximately 80 kg of fresh culture of *M. anisopliae* mixed with 1000 kg of biofertiliser (filter cake) was applied per hectare by spreading into the row at planting (Figure 1). Water was applied as furrow irrigation in every plot.

Field assessments were made at two week intervals beginning one month after planting and until harvest of sugarcane. The total number of *D. buqueti* larvae, the number of infected larvae, and the number of infested stalks in one stool were counted and recorded as one sample. Fifty samples were done in each plot.

The yield of sugarcane in each plot was evaluated. These data were used for evaluating the success of *M. anisopliae* to control *D. buqueti*.

**Results and discussion**

**Field assessment of utilization of *M. anisopliae***

Comparisons between percent infested larvae of *D. buqueti* by *M. anisopliae*, percent infested sugarcane stalks by *D. buqueti* and yield of sugarcane in treated and non-treated plots were indexed to evaluate the success in utilizing *M. anisopliae*.

The efficacy of *M. anisopliae* in controlling *D. buqueti* was obvious when the population of *D. buqueti* was evaluated. The population dynamics of *D. buqueti* in treated plots were of a similar pattern at every location.

Populations decreased one month after application of *M. anisopliae* especially in Rang Ngoen and Rang Sa Ri while the population in non-treated plots increased. It was apparent that the population of *D. buqueti* in treated plots was lower than those in nontreated plots at every location as shown in Figure 2.
Fig. 2—Population of sugarcane longhorn stem borer, *Dorysthenes buqueti* in the treated and non-treated plots of the green muscardine, *Metarhizium anisopliae* plots at Rang Ngoen, Pho Ngoen and Rang Sa Ri districts in 2008.

The percent infected larvae of *D. buqueti* in treated and non-treated plots at every location were evaluated and results are illustrated in Figure 3.

The figure shows that the percent of infected larvae in treated plots was clearly higher than those in non-treated plots during the investigation period March to September 2008 at every location. Infected larvae of *D. buqueti* in treated plots increased after application of *M. anisopliae*, while the infested larvae in non-treated plots did not increase. The highest percent infested larvae was 100% in treated plots at Rang Sa Ri district, Kanchanaburi Province.
Fig. 3—Percent infected larvae of sugarcane longhorn stem borer, *Dorysthenes buqueti* by the green mascardine, *Metarhizium anisopliae* in treated and non-treated plots at Rang Ngoen, Pho Ngoen and Rang Sa Ri districts in 2008.

The average percent infested larvae of *D. buqueti* in treated/non-treated plots at Rang Ngoen and Pho Ngoen, Suphanburi Province were 38.63/6.13 and 25.25/2.86.

In Rang Sa Ri, Kanchanaburi Province these values were 41.67 and 4.49 for treated and non-treated plots respectively.

The average percent infested larvae in treated plots was significantly different from those in non-treated plots at every location as shown in Table 1 and Figure 4. *M. anisopliae* killed on average 35.09±8.68% of the larvae of *D. buqueti* in all treated plots and 4.49±1.64% in all non-treated plots.
Table 1—Average percent infected larvae of sugarcane longhorn stem borer, *Dorysthenes buqueti* by the green mascaline, *Metarhizium anisopliae* in treated and non-treated plots at Rang Ngoen, Pho Ngoen and Rang Sa Ri districts in 2008.

<table>
<thead>
<tr>
<th>Location</th>
<th>Average infected larvae by green mascaline (%)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rang Ngoen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>treated</td>
<td>38.36±31.74&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0–80.00</td>
</tr>
<tr>
<td>non- treated</td>
<td>6.13±13.42&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0–40.00</td>
</tr>
<tr>
<td>Pho Ngoen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>treated</td>
<td>25.25±26.55&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0–75.00</td>
</tr>
<tr>
<td>non- treated</td>
<td>2.86±10.69&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0–40.00</td>
</tr>
<tr>
<td>Rang Sa Ri</td>
<td></td>
<td></td>
</tr>
<tr>
<td>treated</td>
<td>41.67±36.03&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0–100</td>
</tr>
<tr>
<td>non-treated</td>
<td>4.49±12.26&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0–42.85</td>
</tr>
<tr>
<td>All plots</td>
<td></td>
<td></td>
</tr>
<tr>
<td>treated</td>
<td>35.09±8.68</td>
<td></td>
</tr>
<tr>
<td>non-treated</td>
<td>4.49±1.64</td>
<td></td>
</tr>
</tbody>
</table>

Means followed by different letter were significantly different at the 95% probability level.

Yield evaluation from treated and non-treated plots confirms the success of *M. anisopliae* in controlling *D. buqueti*. The yields of sugarcane in treated and non-treated plots from all locations are shown in Table 2. It clear that the yield in treated plots was higher than those in non-treated plots and that these differences were significant at every location. The average yield in all treated plots was 135.6 t/ha while, in all non treated plots, was 72.1 t/ha. The highest yield was 146.3 t/ha at Pho Ngoen district, Suphanburi Province as illustrated in Figure 5. Although the average yields in all treated plots were higher than in non-treated plots, these were still lower than the average yield in the areas not damaged by *D. buqueti*. These findings suggest that further studies in the development of formulations and application of *M. anisopliae*, including identifying important environmental factors affecting the system, are necessary.
**Table 2**—The yield of sugarcane in treated and non-treated plots at Rang Ngoen, Pho Ngoen and Rang Sa Ri districts in 2008.

<table>
<thead>
<tr>
<th>Location</th>
<th>Yield (t/ha)</th>
<th>Range (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rang Ngoen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>treated</td>
<td>137.8±12.2a</td>
<td>126.9–144.9</td>
</tr>
<tr>
<td>non-treated</td>
<td>83.6±9.9b</td>
<td>72.4–98.8</td>
</tr>
<tr>
<td>Pho Ngoen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>treated</td>
<td>138.8±8.4</td>
<td>130.6–146.3</td>
</tr>
<tr>
<td>non-treated</td>
<td>69.7±7.2b</td>
<td>62.4–78.1</td>
</tr>
<tr>
<td>Rang Sa Ri</td>
<td></td>
<td></td>
</tr>
<tr>
<td>treated</td>
<td>130.3±17.8a</td>
<td>115.6–141.3</td>
</tr>
<tr>
<td>non-treated</td>
<td>63.0±6.7b</td>
<td>63.1–70.6</td>
</tr>
<tr>
<td>All plots</td>
<td></td>
<td></td>
</tr>
<tr>
<td>treated</td>
<td>135.6±4.7</td>
<td></td>
</tr>
<tr>
<td>non-treated</td>
<td>72.1±10.5</td>
<td></td>
</tr>
</tbody>
</table>

Means followed by different letter were significantly different at the 95% probability level.

**Fig. 5**—Yield of sugarcane in treated and non-treated plots at Rang Ngoen, Pho Ngoen and Rang Sa Ri districts and average yield in all treated and all non-treated plots in every location in 2008.

**Conclusions**

The application of 80 kg fresh culture of the green muscardine, *M. anisopliae*, mixed with 1000 kg of biofertiliser per hectare during planting of sugarcane will provide effective control of the sugarcane longhorn stem borer, *D. buqueti*. The high numbers of infected larvae of *D. buqueti* and the higher yields of sugarcane in treated plots than in non-treated plots show the efficiency of *M. anisopliae* in controlling *D. buqueti* in Thailand sugarcane fields.

**REFERENCES**

UTILISATION DE LA MUSCARDINE VERTE, *METARHIZIUM ANISOPLIAE*, DANS LA LUTTE CONTRE LE LONGICORNE FOREUR DE TIGE DE LA CANNE À SUCRE *DORYSTHENES BUQUETI* GUERIN (COLEOPTERA: CERAMBYCIDAE)

Par

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Résumé

La muscardine verte, *Metarhizium anisopliae* est utilisée dans la lutte contre le longicorne foreur de tige, *Dorysthenes buqueti*, dans les zones de canne à sucre infestées en Thaïlande. Les champs ont été traités en dispersant une culture de *M. anisopliae* (2.7 × 10^8 spores/g) nouvellement préparée sur le riz cuit. Une seule application de *M. anisopliae* au taux de 80 kg/ha a été faite sur trois sites à Suphanburi et dans la province de Kanchanaburi en 2008. L’effet de la muscardine verte sur les larves du longicorne foreur de tige et sur le rendement de canne a été évalué. Les résultats ont montré que l’application du champignon tuait en moyenne 35.09±8.68% des larves du foreur dans toutes les parcelles traitées et 4.49±1.64% dans toutes les parcelles non-traitées. La moyenne la plus élevée de larves infestées était de 41.67±36.03% au district de Rang Sa Ri, dans la province de Kanchanaburi. Le rendement de canne était en moyenne de 135.61±4.67 t/ha dans les parcelles traitées, alors que celui des parcelles non-traitées était en moyenne de 72.11±10.51 t/ha. Cette étude démontre que *M. anisopliae* est un agent efficace de lutte biologique contre le longicorne foreur de tige en Thaïlande.


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Palabras clave: Control Biológico, *Metarhizium anisopliae*, Hongos Entomopatógenos, Barrenador del Tallo de Antenas Largas de la Caña de Azúcar.

Resumen

La muscardina verde, *Metarhizium anisopliae* se utiliza en el control del barrenador de antenas largas del tallo, *Dorysthenes buqueti*, en áreas infestadas de cultivos de caña de azúcar en Tailandia. Los campos se trataron asperjando cultivos frescos de *M. anisopliae* cultivado en un sustrato de arroz cocido (2.7 × 10⁸ esporas/g). Una sola aplicación de *M. anisopliae* en la dosis de 80 kg/ha se hizo en tres localidades en las Provincias de Suphanburi y Kanchanaburi en 2008. Se evaluó el efecto del hongo sobre las larvas del barrenador, así como la producción de caña de azúcar. Los resultados mostraron que, después de la aplicación del hongo, este mató en promedio 35.09±8.68% de las larvas del barrenador en todas las parcelas tratadas, observándose una mortalidad de 4.49±1.64% en las parcelas no tratadas. El porcentaje más alto de infestación por las larvas fue de 41.67±36.03%, en el distrito de Rang a Ri, de la Provincia Kanchanaburi. El promedio de producción de la caña de azúcar fue de 135.61±4.67 t/ha en las parcelas tratadas, mientras que en las parcelas no tratadas, la producción promedia fue 72.11±10.51 t/ha. Estos resultados indican que *M. anisopliae* fue un controlador biológico efectivo en el control de este barrenador de la caña de azúcar en Tailandia.
POTENTIAL IMPACT OF MEXICAN RICE BORER NON-CROP HOSTS ON SUGARCANE IPM

By

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KEYWORDS: Eoreuma loftini (Dyar), Integrated Pest Management, Alternate Hosts.

Abstract

The Mexican rice borer, Eoreuma loftini (Dyar) (Lepidoptera: Crambidae), was detected in Louisiana in 2008, having first spread from Mexico into Texas. E. loftini is a severe pest of sugarcane, but it also feeds on rice and a wide range of other grasses. Research on E. loftini management has focused on studying the pest in its main crop host plants, with the role of non-crop grasses only recently studied. Two four-replication sentinel plant studies were conducted in 2006 and 2007 to assess naturally occurring E. loftini infestations in five selected weed species: Leptochloa panicoides, Sorghum halepense, Paspalum urvillei, Urochloa platyphylla and Echinochloa crus-galli. Results showed that L. panicoides, a common weed in Louisiana rice fields, was a highly suitable host, harbouring the highest E. loftini infestations with as many as 78% of the plants infested with at least one larva. In addition, S. halepense and P. urvillei, two ubiquitous perennial grasses, also supported complete larval development of E. loftini. On the other hand, both U. platyphylla and E. crus-galli, which are two common weeds in and near rice fields in Louisiana, proved to be poor E. loftini host plants. Continuous pheromone trapping in the southeast Texas rice area showed that adult moths are active throughout the year. Our studies showed that non-crop hosts could play a key role in E. loftini population build-up, thus warranting a better characterisation of E. loftini source-sink interactions in Louisiana sugarcane producing areas. The manipulation of E. loftini non-crop sources has the potential to decrease a significant proportion of area-wide populations, minimising damaging infestations in sugarcane fields.

Introduction

The Mexican rice borer, Eoreuma loftini (Dyar) (Lepidoptera: Crambidae), is indigenous to Mexico and was first reported in 1980 in south Texas (Johnson, 1984). This borer quickly became the most damaging insect pest of sugarcane (Saccharum spp. hybrids) in the Lower Rio Grande Valley of Texas, where it represents more than 95% of stem borer infestations (Legaspi et al., 1997). After expanding its range in a northeast direction along the Gulf Coast (Reay-Jones et al., 2007b), E. loftini has also become an increasing problem for rice (Oryza sativa) production in southeast Texas. E. loftini was detected in Louisiana for the first time in December 2008 (Hummel et al., 2008), representing a serious threat to the state’s sugarcane and rice industries. The imminent establishment of E. loftini in Louisiana sugarcane producing areas encouraged proactive studies that integrate cultivar resistance, biorational insecticides, and irrigation-based population suppression to develop an effective management program (Reay-Jones et al., 2005). Insecticides and cultivar
resistance have also been studied in rice, which is also grown in sugarcane areas of Louisiana. In addition to crop hosts, Van Zwalunwenburg (1926) stated that *E. loftini* ‘attacks practically all the grasses large enough to afford it shelter within the stalk’. Non-crop grasses may therefore play a role in the overwintering and build-up of *E. loftini* populations, and should be integrated into the development of new cultural practices for an improved pest management program. This paper reports on initial studies with *E. loftini* non-crop hosts and discusses their possible importance in future sugarcane integrated pest management (IPM) for Louisiana.

**Material and methods**

**Sentinel plant experiments**

Two sentinel plant experiments were designed to compare *E. loftini* infestation development on selected non-crop grass species under natural infestations. Experiments were conducted in southeast Texas during 2006 and 2007 near Ganado (N 29.0267°, W 96.4394°) and Hankamer (N 29.8554°, W 94.5451°), respectively, where *E. loftini* populations naturally occur at high densities.

Five weed species that are abundant in or near sugarcane and rice fields and have the potential to host *E. loftini* populations were studied (Table 1). Rice (cultivar Cocodrie) served as a control. Seeds were obtained from Azlin Seed Service (Leland, MS), except for *Paspalum urvillei* seeds that were collected in Lafayette Parish, LA. Plants were grown in a greenhouse in 7.57 L pots, each containing eight (2006) or six (2007) evenly spaced plants. In mid-August, after growing for two months under greenhouse conditions, the potted plants were placed in a rice field near a levee. For each plant species, six pots constituted a plot, and plots were arranged in a randomised complete block design with four blocks (1 replication per block). Plots were separated by 75 cm (2006) or 2 m (2007) spaces. Plants remained in the pots, but pot bottoms were removed to facilitate better equalisation with field moisture conditions.

In 2006, ten plants from each plot were randomly selected and cut at the base both four and nine weeks after transplanting. In 2007, 12 plants were sampled both four and seven weeks after transplanting. Each tiller was measured and the number of leaves counted. Plants were observed for borer feeding signs and dissected for the presence of larvae and pupae.

Statistical analyses were performed using Proc GLIMMIX (SAS Institute, 2008). Generalised linear mixed models (GLMMs) with an over-dispersion parameter were used to analyse the proportion of plants infested with *E. loftini* (binomial distribution) and *E. loftini* abundance as affected by plant species (Poisson distribution). Because sugarcane borers, *Diatraea saccharalis* (F.), also infested sentinel plants in 2006, a GLMM with a binomial distribution was used to compare borer species composition as affected by the plant species. The Kenward-Roger adjustment for denominator degrees of freedom was used in all models to correct for inexact *F* distributions.

**Adult pheromone trapping**

Male *E. loftini* moths were continuously monitored to determine seasonal patterns of flight activity. From April 2007 to April 2009, monitoring was conducted at three sites in southeast Texas. Two standard universal pheromone traps were used at each site according to the method of Reay-Jones *et al.* (2007b). Traps were located near the Texas AgriLIFE Research Center at Beaumont (N 30.0672°, W 94.2932°), and near Hankamer and Ganado where the two sentinel plant experiments were conducted. Traps were checked for *E. loftini* moths every two-to-three weeks, and trap catches were estimated on a daily basis for each sampling period (Reay-Jones *et al.*, 2007b).

**Results**

**Sentinel plant experiments**

The five grass weed species used as sentinel plants presented a diverse range of height, number of tillers, and leaf availability (Table 1). In 2006, four weeks after transplanting to the field, rice, *S. halepense*, *E. crus-galli*, and *U. platyphylla* were either heading or showing maturing
flowerheads, whereas \textit{L. panicoides} was senescent. \textit{P. urvillei}, which had a slow germination rate, was still in a vegetative stage. Nine weeks after transplanting, \textit{L. panicoides}, \textit{E. crus-galli}, and \textit{U. platyphylla}, all three annual grasses, had completed their life cycles and had died. Rice was senescent whereas \textit{S. halepense} and \textit{P. urvillei}, two perennial grasses, showed a mixture of senescent and maturing leaf and stem tissues.

\begin{table}
\centering
\begin{tabular}{|l|l|l|l|l|l|l|l|l|l|l|}
\hline
\textbf{} & \textbf{Oryza sativa} & \textbf{Sorghum halepense} & \textbf{Paspalum urvillei} & \textbf{Leptochloa panicoides} & \textbf{Echinochloa crus-galli} & \textbf{Urochloa platyphylla} \\
\hline
\textbf{Height (cm)} & 63.4 & 38.5 & 97.4 & 75.0 & 27.3 & 37.2 & 53.8 & – & 85.9 & – & 54.3 & – \\
\hline
\textbf{No. tillers / plant} & 1.8 & 3.2 & 1.7 & 1.3 & 2.6 & 5.5 & 1.5 & – & 1.9 & – & 3.3 & – \\
\hline
\textbf{No. total leaves / plant} & 9.9 & 10.2 & 10.3 & 3.4 & 10.2 & 18.3 & 9.5 & – & 12.7 & – & 22.2 & – \\
\hline
\textbf{No. green leaves / plant} & 5.1 & 6.4 & 5.4 & 2.6 & 9.0 & 12.9 & 1.9 & – & 4.9 & – & 7.4 & – \\
\hline
\end{tabular}
\end{table}

Each grass species harboured at least some stage of \textit{E. loftini} larvae. In addition, the grasses also harboured \textit{D. saccharalis} larvae. Depending on the grass species, \textit{E. loftini} represented 48% to 73% and 74% to 93% of the recovered borers after four and nine weeks, respectively. However, the proportion of \textit{E. loftini} versus \textit{D. saccharalis} was not affected by the grass species ($F= 0.37; df= 5, 12.25; P= 0.857$ after 4 weeks and $F= 0.66; df= 2, 4.615; P= 0.558$ after 9 weeks). After four weeks under natural infestations, there were differences in the proportion of plants infested with \textit{E. loftini} ($F= 3.94; df= 5, 15; P= 0.018$) and the number of \textit{E. loftini} per plant ($F= 3.45; df= 5, 18; P= 0.023$) as affected by the plant species. \textit{L. panicoides} was numerically the most infested species (Figures 1 and 2). \textit{E. loftini} fourth and larger instars represented 61.5% (LS mean) of the recovered immatures. \textit{E. loftini} pupae and pupal casings, indicating completion of life cycle, represented 19.8% (LS mean) of the fourth instars and larger immatures, hereafter referred to as late instars. Infestations in rice and \textit{S. halepense} were not different from \textit{L. panicoides} although numerically trending lower. \textit{E. loftini} late instars represented 19.4% and 5.6% (LS means) of the immatures recovered in rice and \textit{S. halepense}, respectively, with no pupae observed. \textit{U. platyphylla} harboured less infestation compared to \textit{L. panicoides}, but was not different from the other grasses. \textit{E. loftini} late instars represented 25% (LS mean) of the immatures recovered from \textit{U. platyphylla}, with one pupa observed. However, this pupa was in a folded flag leaf, suggesting that the original larvae possibly came from another plant. \textit{E. crus-galli} and \textit{P. urvillei} harboured the lowest \textit{E. loftini} infestations (Figures 1 and 2). Pupae were not found in \textit{E. crus-galli}, however; 12.5% (LS mean) of the recovered immatures were late instars. No late instars were recovered from \textit{P. urvillei}. Five weeks later, there were trends ($F= 2.62; df= 2, 9; P= 0.127$) for a greater proportion of \textit{E. loftini} infested rice plants, in comparison to \textit{S. halepense} and \textit{P. urvillei} plants (Figure 1). When considering the overall number of \textit{E. loftini} per plant, rice also showed a strong trend ($F= 5.00; df= 2, 5.711; P= 0.056$) for greater borer densities (Figure 2). In rice, \textit{S. halepense}, and \textit{P. urvillei} pupae
and pupal casings represented respectively 60.4%, 22.5%, and 12.5% (LS means) of the recovered *E. loftini*, indicating completion of the life cycle.

In 2007, four weeks after transplanting to the field, all plants were either heading or had maturing flowerheads. Seven weeks after transplanting, all plants exhibited maturing flowerheads, except *L. panicoides*, which was senescent. Almost exclusively, *E. loftini* infested the sentinel plants. However, three *D. saccharalis* larvae were recovered from *L. panicoides* plants collected from the same plot. All grasses except *U. platyphylla* were infested with *E. loftini* (Figures 1 and 2). The proportion of plants infested after four weeks (*F* = 10.40; df = 5, 15.06; *P* < 0.001) and seven weeks (*F* = 8.83; df = 5, 18; *P* < 0.001) changed with the plant species, as well as the number of *E. loftini* per plant (*F* = 2.061; df = 5, 14.82; *P* = 0.001 after 4 weeks and *F* = 15.02; df = 5, 18; *P* < 0.001 after 7 weeks). *L. panicoides* harboured the highest *E. loftini* infestations (Figure 1 and 2).

Late instars were found only in *L. panicoides*, representing 25% (LS mean) of the larvae collected. No pupae were recovered after four weeks in the field. Three weeks later, the late instars observed in *L. panicoides*, rice, *E. crus-galli*, and *P. urvillei* represented 59.1%, 31.3%, 10% and
6.3% (LS means) of the recovered *E. loftini*. Only *L. panicoides* and rice had allowed completion of *E. loftini* life cycle, with five and one pupae or pupal casings recovered, respectively representing 13.8% and 8.3% of the *E. loftini* late instars found in each grass.

**Adult pheromone trapping**

Pheromone trapping showed that moth flight activity reached its peak between September and November while it was at a minimum between December and February (Figure 3). The highest *E. loftini* moth numbers were caught from the Hankamer site with 72.9 moths/trap/day for the November 2, 2008 sampling period.

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**Fig. 3**—Male *E. loftini* pheromone trap catches estimated on a daily basis near Beaumont (a), Hankamer (b), and Ganado (c), Texas, April 2007–April 2009.
An early spring flight activity peak was recorded at the three trapping sites in March 2009. For the March 16 sampling period, 25.8 moths/trap/day were collected near Beaumont. For the Hankamer and Ganado sites, trap catches were 27.2 moths/trap/day for the March 22 period and 23.6 moths/trap/day for the March 7 period, respectively.

At the Beaumont site, *E. loftini* moths were not caught over more than two subsequent samplings from December 23, 2007 to March 10, 2008. At the Hankamer site, *E. loftini* moths were not caught over more than two subsequent samplings from January 21, 2008 to February 11, 2008. During the winter from 2008 to 2009, there were no two subsequent dates with zero catches at the Beaumont and Hankamer sites. Further south near Ganado, although trap catches were reduced somewhat in December and January, *E. loftini* moths were active all year long with no two subsequent dates of zero catches.

**Discussion**

The impacts on arthropod population dynamics of non-crop plants occurring in an agroecosystem are complex and far from following a general principle (Norris and Kogan, 2005). Non-crop plants may offer shelter for predators, and both shelter and food for their prey, increasing natural enemy density and subsequently decreasing pest populations (Letourneau, 1987; Russell, 1989). Conversely, non-crop plants may also serve as hosts and emit host-finding stimuli for crop pests, increasing pest populations (Karban, 1997, Tindall *et al.*, 2004). Our sentinel plant experiments showed that non-crop grasses could host *E. loftini*. Additional sampling of non-crop habitats near southeast Texas rice fields in February yielded *E. loftini* densities attaining as many as four immatures per m² (JMB, data not shown).

A plant is a host if both herbivore feeding and completion of the herbivore life cycle occur. *L. panicoides*, a weed in Louisiana rice fields, is a highly suitable host. Because *D. saccharalis* injury to rice is higher in plots surrounded by *L. panicoides* (Tindall, 2004), this grass may also enhance *E. loftini* infestations in surrounding areas. With no strong evidence of *E. loftini* completing its life cycle in *U. platyphylla* and *E. crus-galli*, two common weeds in and near rice fields, the contribution of these grasses to *E. loftini* population pressure seems small. Plant morphological (e.g., pubescence, stem hardness and diameter, abundance of dry leaves) and biochemical (e.g., primary metabolites, allelochemicals) factors affect stem borer oviposition preference and larval performance (Martin *et al.*, 1975, Sosa, 1990, Meagher *et al.*, 1996, Reay-Jones *et al.*, 2007a). Among other factors, the relatively smaller stem diameter of *U. platyphylla* and *E. crus-galli* likely contributes to the lack of suitability as a host for *E. loftini*.

Plant availability over time also plays a major role in the use of non-crop grasses as hosts by *E. loftini*. *S. halepense*, a ubiquitous grass in weedy areas and sugarcane fields, was infested with *E. loftini* in both sentinel plant experiments and winter samplings of non-crop habitats (JMB, data not shown). With all borer life stages recovered and infestations not differing from those in rice in the sentinel plant experiments, *S. halepense* is certainly a primary non-crop host. Bynum *et al.* (1938) concluded that if not mowed often, *S. halepense* could provide overwintering shelter for *D. saccharalis* and would be a source for spring infestations in Louisiana sugarcane. Another common perennial grass in weedy areas, *P. urvillei*, was heavily infested in samplings of non-crop habitats during the winter (JMB, data not shown), whereas not particularly infested in the sentinel plant experiments. From these observations, *P. urvillei* may not be a preferred host although suitable. *P. urvillei* plants grow large over the years and offer green material during the winter when other grasses are dry or too small (e.g., *S. halepense*). Despite reduced numbers during the winter, *E. loftini* adults fly during any season. The difference in plant availability may therefore explain *E. loftini* aggregation in *P. urvillei* plants during the winter; hence, *P. urvillei* is certainly a primary non-crop host.

Our studies were conducted in southeast Texas agroecosystems where rice is a dominant crop. Results suggest that non-crop hosts could play a role in *E. loftini* population dynamics. Weeds
differ in their life cycles (annual vs. perennial), timing of seasonal development, and habitat (crop fields vs. crop field margins, roadsides, ditches, or canal banks). Thus, the relative importance of each non-crop host species may change with time of the year, geographical area, and the dominant crop. The manipulation of *E. loftini* non-crop sources may decrease a significant proportion of area-wide populations, decreasing infestations in sugarcane fields. Thus, our studies warrant a better characterisation of the influence of non-crop hosts as *E. loftini* sources in Louisiana sugarcane. Ongoing research includes periodical non-crop habitat sampling and *E. loftini* oviposition preference and larval performance studies. Our ultimate goal is to incorporate findings from studies reported in this paper and ongoing research into a model that will simulate different weed management strategies (e.g., mowing, biorational insecticide applications) and predict their impact on *E. loftini* area-wide populations, thereby improving the overall sugarcane area IPM.

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IMPACT POTENTIEL DES PLANTES HÔTES NON CULTIVÉES SUR LA LUTTE INTÉGRÉE CONTRE LE FOREUR DES TIGES EOREUMA LOFTINI (DYAR) DANS LA CANNE À SUCRE

Par

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MOTS CLES: Eoreuma loftini (Dyar), Lutte Intégrée, Hôtes non Cultivés.

Résumé

APRÈS avoir envahi le Texas à partir du Mexique, le foreur des tiges Eoreuma loftini (Dyar) a été détecté en Louisiane en 2008. *E. loftini* est un sérieux ravageur de la canne à sucre, mais il attaque aussi de nombreuses autres graminées. La recherche pour lutter contre ce ravageur s’est concentrée sur les insectes attaquant les plantes cultivées, le rôle des infestations dans les mauvaises herbes n’ayant été que récemment étudié. Une étude de deux ans a déterminé les infestations d’*E. loftini* sur cinq graminées non cultivées: *Leptochloa panicoides*, *Sorghum halepense*, *Paspalum urvillei*, *Urochloa platyphylla* et *Echinochloa crus-galli*. *L. panicoides*, une mauvaise herbe dans les rizières en Louisiane, est une plante hôte très adéquate, abritant les infestations les plus élevées avec jusqu’à 78% des plantes infestées avec au moins une larve. Avec *L. panicoides*, *S. halepense* et *P. urvillei*, deux herbes pérennes, étaient les seules à permettre la complétion du cycle biologique de l’insecte. *U. platyphylla* et *E. crus-galli*, deux mauvaises herbes communes dans les rizières et leurs alentours, étaient des hôtes peu adéquats. Le piégeage à l’aide de phéromones a montré que les adultes volent tout au long des saisons. Ces études menées au sud-est du Texas ont montré que les graminées non cultivées pourraient jouer un rôle dans la croissance des populations d’*E. loftini*, justifiant une meilleure caractérisation de ce rôle dans les zones cannières de Louisiane. La manipulation des hôtes non cultivés a le potentiel de diminuer les populations du foreur, minimisant les infestations qui endommagent les champs de canne à sucre.
IMPACTO POTENCIAL DEL BARRENADOR MEXICANO DEL ARROZ EN HOSPEDANTES ALTERNOS EN UN MIP DE CAÑA DE AZUCAR

Por

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PALABRAS CLAVE: \textit{Eoreuma loftini} (Dyar), Manejo Integrado de Plagas, Hospedantes Alternos.

Resumen

El barrenador mexicano del arroz, \textit{Eoreuma loftini} (Dyar) (Lepidoptera: Crambidae), se detectó en Luisiana en 2008, siendo la primera vez que se dispersa de México a Texas. \textit{E. loftini} es una plaga muy seria de la caña de azúcar, pero también se alimenta de arroz y otra serie de gramíneas. La investigación sobre el manejo de \textit{E. loftini} se ha concentrado en el estudio de la plaga en su principal hospedante y solo recientemente se ha puesto interés en el papel que juegan los pastos no cultivados. Dos estudios con plantas centinelas con cuatro repeticiones se condujeron en 2006 y 2007 para evaluar la ocurrencia natural de infestaciones de \textit{E. loftini} en cinco especies de malezas, \textit{Leptochloa panicoides}, \textit{Sorghum halepense}, \textit{Paspalum urvillei}, \textit{Urochloa platyphylla} y \textit{Echinochloa crus-galli}. Los resultados mostraron que \textit{L. panicoides}, una maleza común en campos de arroz de Luisiana, fue un hospedante muy apropiado, albergando las infestaciones más altas de \textit{E. loftini}, llegando hasta un 78\% de las plantas con al menos una larva. Además, \textit{S. halepense} y \textit{P. urvillei}, dos gramíneas perennes muy ubicuotas, también soportaron el desarrollo completo larval de \textit{E. loftini}. Por otra parte, tanto \textit{U. platyphylla} como \textit{E. crus-galli}, que son malezas comunes en y cerca de campos de arroz en Luisiana, probaron ser muy pobres como plantas hospedantes de \textit{E. loftini}. Un trampeo continuo con feromonas en el sureste del área arrocera de Texas mostró que las polillas adultas se mantienen activas a través del año. Nuestros estudios mostraron que plantas no cultivadas pueden jugar un papel muy importante en el incremento de las poblaciones de \textit{E. loftini}, proporcionando así un mejor conocimiento sobre la fuente de \textit{E. loftini} en las interacciones con las áreas productoras de caña de azúcar en Luisiana. La manipulación de las plantas no cultivadas que albergan poblaciones de \textit{E. loftini} tiene un potencial para disminuir en proporción significativa las poblaciones, minimizando así las infestaciones que dañen los campos de caña de azúcar.
SUGARCANE RESPONSE TO TWO BIOTIC STRESSORS: 
**DIATRAEA SACCHARALIS AND MAHANARVA FIMBRIOLATA**

By

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KEYWORDS: Sugarcane Borer, Spittlebug, Insect-Plant Relationship, Yield.

Abstract

The sugarcane borer (*Diatraea saccharalis*) and spittlebug (*Mahanarva fimbriolata*) are considered important sugarcane pests in South America. Damage caused by these pests has already been studied for each species separately; however, knowledge of sugarcane’s response to attack by these two pests combined as well as the effect on sugarcane yield has not. The aim of this work was to evaluate the plant response to infestations of these two biotic stressors. Treatments comprised high and low sugarcane borer infestations, spittlebug infestation, both sugarcane borer and spittlebug infestations combined, and controls (uninfested plants). Plots comprised 2 m² caged and uncaged sugarcane stalks. Damage attributed to spittlebug nymph attack alone, or in combination with borer attack, decreased the diameter of the stalks. When compared to the control (caged stalks), such damage resulted in a significant reduction in yield: (17.6%) from stalks that were attacked by spittlebug nymphs alone; (15.5%) from spittlebug nymphs + sugarcane borer combined and (6.9%) from sugarcane borer alone. There was no significant difference among the treatments in levels of soluble solids and apparent sucrose. However, when evaluating the sucrose yield per unit area, spittlebugs did affect sugar production (individually and in combination with the borer). Therefore, infestation by these pests does lead to yield reduction in the sugarcane crop.

Introduction

The sugarcane borer, *Diatraea saccharalis* (Fabricius, 1794) (Lepidoptera: Crambidae), is a key pest of sugarcane and occurs in several countries of the Americas, including Brazil where it is distributed in all producing regions (Gagliumi, 1973; White et al., 2008). Also, due to the increase of mechanical harvest (green cane) and decrease of traditional system (burned cane), the trash layer that is kept on the soil surface has brought changes in environmental characteristics within the sugarcane habitat. These changes have favoured an increase in populations of the spittlebug *Mahanarva fimbriolata* (Stål, 1854) (Hemiptera: Cercopidae), a native pest which is now also considered a key pest of sugarcane in Brazil (Dinardo-Miranda et al., 2001; Mendonça et al., 1996).

In spite of the importance of the two sugarcane pests and their simultaneous occurrence, mainly during the rainy season, there is no information on how sugarcane responds to these pests combined (biotic stress). Current information on plant-insect response aiming at implementing
economic thresholds is usually from infestations where only one pest was present or where one pest was kept under control (White et al., 2008; Madaleno et al., 2008).

According to Peterson and Higley (2001), stress interactions represent the potential relationships among different agents that produce stress in a plant. Thus, the knowledge of infested plant response by two pests combined (e.g.: spittlebug and sugarcane borer) can be an important tool for decision making. Therefore, the aim of this work was to evaluate the sugarcane plant response where both biotic stressors were present.

**Material and methods**

The experiment was carried out in the São Martinho Sugar Mill, located in São Paulo State, Brazil, (21º19’S and 48º06’W), from December 2007 to October 2008. The variety selected was SP80-3280 (4th ratoon), which is susceptible to spittlebug and sugarcane borer (Dinardo-Miranda, 2003).

The trial was a randomised complete block design with six treatments and four replications. Each plot comprised a 2 m row of sugarcane. Plots were individually protected using a cage structure surrounded by voile fabric to prevent insect movement, except the unprotected control (check). However, when the cages were placed over the plants (72 days after harvest), stalks already bored by sugarcane borer were noticed. Thus, plants were naturally infested. Pests were monitored on every stalk at 2 to 3-day intervals.

Treatments comprised single or combined infestations of spittlebug and sugarcane borer at different levels of Infestation Intensity (I.I.) as follows: high sugarcane borer infestation (I.I.: 15.80%), low sugarcane borer infestation (I.I.: 2.75%), spittlebug nymph infestation (3.07 nymphs/m), both sugarcane borer and spittlebug nymph infestation (I.I.: 13.63% and 2.95 nymphs/m), caged control (I.I.: 0.12% and 0.60 nymphs/m) and unprotected control (check). In spite of an effort to have no spittlebug infestation on sugarcane borer only infested plots, a very low infestation was observed (0.64 nymphs/m). This was attributed to the resident soil population of this pest. Similarly, plots that should have only spittlebug infestations, were also infested by sugarcane borer before cage placement. However, infestation levels were also very low (II: 3.07%).

The stalks were manually harvested around three hundred days after ratoon emergence (nine months after the infestation started). All stalks (n=25) were taken from each plot and their weight, length, and diameter recorded. Stalks were then shredded and juice extracted using a hydraulic press, as suggested by Tanimoto (1964). Immediately after the extraction, the level of soluble solids (Brix) and the apparent sucrose (Pol) were determined according to Scheneider (1979). The sucrose yield per area was estimated using the sucrose content (Pol) and the stalk yield.

Data were analysed (Anova) and means compared using LSD (P = 0.05).

**Results and discussion**

Spittlebug injury negatively affected (F=3.27, P=0.034) the diameter of stalks (Table 1). The stalks infested by spittlebugs, either individually or in combination with the sugarcane borer, were significantly shorter and thinner than non-infested stalks. Feeding by spittlebug nymphs results in plant dehydration, lower nutrition, and possibly plant death (Dinardo-Miranda, 2003).

As the spittlebug affected stalk characteristics, yield was significantly lower (F=3.45, P=0.0284) than yield from non-infested stalks. This was also noted for stalks infested by spittlebugs alone or infested by both spittlebugs and sugarcane borer. On the other hand, stalks infested only by sugarcane borer did not show a significant reduction in stalk yield, compared to the controls (protected and unprotected stalks). The stalk yield losses due to borer infestation is 1.14% per each 1% of infestation intensity (CTC, 2007).

In spite of different pest infestations, all caged plants had similar levels of Brix; however, uncaged plants had significantly higher Brix than caged plants (F=10.64, P=0.0002). However, the
apparent sucrose content (Pol) varied among treatments (F=14.66, P<0.0001). The lowest Pol level was observed in stalks infested by both pests and was 8.37% lower than the level noted in non-infested uncaged stalks.

Table 1—Biometric parameters, soluble solids (Brix), apparent sucrose (Pol) and sucrose yield per area under *Diatraea saccharalis* and *Mahanarva fimbriolata* infestations.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Diameter of stalk (cm)</th>
<th>Length of stalk (cm)</th>
<th>Stalk yield (t/ha)</th>
<th>Brix (%)</th>
<th>Pol (%)</th>
<th>Sucrose yield per area (t pol/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugarcane borer (high Infestation)</td>
<td>2.43 ab</td>
<td>258.63 a</td>
<td>116.85 ab</td>
<td>21.93 b</td>
<td>19.63 bc</td>
<td>22.96 bc</td>
</tr>
<tr>
<td>Sugarcane borer (low Infestation)</td>
<td>2.41 ab</td>
<td>261.86 a</td>
<td>116.85 ab</td>
<td>22.30 b</td>
<td>20.08 b</td>
<td>23.44 abc</td>
</tr>
<tr>
<td>Spittlebug</td>
<td>2.32 b</td>
<td>245.44 a</td>
<td>103.41 b</td>
<td>22.22 b</td>
<td>20.08 b</td>
<td>20.79 c</td>
</tr>
<tr>
<td>Spittlebug + sugarcane borer</td>
<td>2.36 b</td>
<td>248.47 a</td>
<td>106.04 b</td>
<td>21.78 b</td>
<td>19.27 c</td>
<td>20.42 c</td>
</tr>
<tr>
<td>Control (caged)</td>
<td>2.49 a</td>
<td>272.82 a</td>
<td>125.54 a</td>
<td>21.73 b</td>
<td>19.50 bc</td>
<td>24.50 ab</td>
</tr>
<tr>
<td>Control (uncaged)</td>
<td>2.49 a</td>
<td>267.29 a</td>
<td>125.85 a</td>
<td>23.51 a</td>
<td>21.03 a</td>
<td>26.46 a</td>
</tr>
</tbody>
</table>

| P  | 0.034 | 0.0965 | 0.0284 | 0.0002 | < 0.0001 | 0.0077 |
| F_{Trat} | 3.27* | 2.30^{NS} | 3.45* | 10.64** | 14.66** | 4.86** |
| CV | 3.17  | 5.39   | 8.8    | 1.82    | 1.64    | 8.94   |

Means within a column indicated by different letters are significantly different (LSD test, P<0.05).

Pol was not significantly different between stalks infested by either pest separately. Stalks infested by spittlebug, either individually or combined with the sugarcane borer, resulted in a lower sucrose yield per unit area than stalks without any pest infestation (F = 4.86, P = 0.0077). Spittlebug infestation caused a 15.14% to 16.65% reduction in sucrose yield per hectare.

Overall, plants infested by spittlebug, either associated with or without the sugarcane borer, were severely damaged. On the other hand, the sugarcane borer did not seem to affect the yield. However, the sucrose yield was affected and may be related to the influence of fungi (*Colletotrichum* and *Fusarium* spp.) associated with the sugarcane borer and different infestation levels. Severe infestations of the sugarcane borer result in longer galleries in the stalk, and a greater likelihood of fungal occurrence. These fungi are responsible for sucrose inversion and production of metabolite inhibitors (McGuire *et al.*, 1965; Stupiello & Moraes, 1974; Blumer, 1992) which can lead to even greater yield reductions. Technological parameters such as sugar production and quality should also be evaluated. This information will be very important to enhance the current threshold levels adopted to control these pests in Brazil.

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**REPOINSE DE LA CANNE À SUCRE A DEUX BIOAGRESSEURS: DIATRAEA SACCHARALIS ET MAHANARVA FIMBRIOLATA**

Par

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**MOTS CLÉS: Foreur de la Canne, Cicadelle Ecumeuse, Relation Plante-Insecte, Rendement.**

**Résumé**

Le foreur de la tige (*Diatraea saccharalis*) et la cicadelle écumeuse (*Mahanarva fimbriolata*) sont considérés comme les ravageurs majeurs de la canne à sucre en Amérique du Sud. Les dégâts causés ont déjà été étudiés séparément pour les deux espèces. Toutefois, nos connaissances sur la réaction de la canne à sucre à l’infestation simultanée par ces deux ravageurs et leur effet sur le rendement ne sont pas connues. L’objectif de cette étude a été d’évaluer la réponse de la canne à l’infestation de ces deux bioagresseurs. Les traitements comprenaient les niveaux faibles et élevés d’infestation du foreur, l’infestation par la cicadelle écumeuse, une combinaison des infestations de ces deux bioagresseurs, et un témoin (plantes non-infestées). Les parcelles comportaient des tiges...
de canne sur 2 m², encagées et non-encagées. Les dégâts attribués uniquement aux nymphes de la cicadelle écumeuse ou en combinaison avec une attaque du foreur, ont occasionné une réduction du diamètre de la tige. Par rapport au témoin (tiges encagées), ces dégâts ont eu un effet significatif sur le rendement avec les résultats suivants: tiges attaquées par les nymphes de la cicadelle écumeuse : 17.6%, effets combinés des nymphes de la cicadelle écumeuse + foreur de la tige: 15.5% et foreur de la tige seulement: 6.9%. Aucune différence parmi les traitements n’a été observée au niveau des sucres solubles et du saccharose apparent. Toutefois, la cicadelle écumeuse a significativement affecté le rendement en sucre par unité de surface (seul ou en combinaison avec le foreur). Par conséquent, l’infestation due à ces deux ravageurs peut affecter le rendement de la canne à sucre.

LA RESPUESTA DE LA CAÑA DE AZÚCAR A DOS FACTORES DE ESTRÉS BIÓTICO: DIATRAEA SACCHARALIS Y MAHANARVA FIMBRIOLATA

Por

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Resumen

El barrenador de la caña de azúcar (Diatraea saccharalis) y salivazo (Mahanarva fimbriolata) son considerados plagas importantes de la caña de azúcar en América del Sur. Los daños causados por estas plagas ya ha sido estudiado para cada especie por separado, sin embargo, el conocimiento de la respuesta a los ataques de estas dos plagas en forma combinada, así como el efecto sobre la producción en la caña de azúcar no se tienen resultados. El objetivo de este trabajo fue evaluar la respuesta de la planta a las infestaciones de estos dos factores de estrés biótico. Los tratamientos comprendieron altas y bajas infestaciones del barrenador de la caña de azúcar y del salivazo, solos y como combinados y los controles (plantas no infestadas). Las parcelas comprendieron tallos en jaulas de 2 m² y tallos sin enjaular. El daño atribuido al ataque de las ninfas de salivazo, solo o en combinación con el ataque del barrenador, disminuyó el diámetro de los tallos. Cuando se compararon estos resultados con el control (tallos en jaulas), los daños ocasionaron disminuciones significativas de la producción: (17.6%), cuando los tallos fueron atacados únicamente por las ninfas del salivazo; (15.5%) cuando las ninfas de salivazo y barrenador de la caña de azúcar en combinado y (6.9%) cuando fue solo el barrenador de la caña de azúcar. No hubo diferencias significativas entre los tratamientos en los niveles de sólidos solubles y sacarosa aparente. Sin embargo, al evaluar la producción de sacarosa por unidad de área, se encontró que el salivazo afectó la producción de azúcar (individualmente y en combinación con el barrenador). Por tanto, la infestación por estas plagas se traduce en la reducción de productividad en el cultivo de caña de azúcar.
A NUTRITIONAL PERSPECTIVE OF SUGARCANE RESISTANCE TO STALK BORERS AND SAP FEEDERS

By

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KEYWORDS: Eoreuma loftini, Melanaphis sacchari, Saccharum spp., Free Amino Acids, Cultivar Resistance.

Abstract

TWO RELATIVELY new key species in Louisiana that conform to the plant stress hypothesis are the Mexican rice borer, Eoreuma loftini (Dyar) and the sugarcane aphid, Melanaphis sacchari (Zehntner). High performance liquid chromatography differentiated insect resistant and susceptible sugarcane cultivars based on nutritional profiles involving free amino acids (FAAs). For E. loftini susceptible cultivar LCP 85-384, concentrations of essential and nonessential FAAs in whole leaf tissue samples were more than twice as high as in the resistant cultivar HoCP 85-845. Similarly, M. sacchari susceptible L 97-128 exhibited more than three fold higher concentrations of essential FAAs in the phloem sap compared to the resistant cultivar, HoCP 91-555. Two essential FAAs, histidine and arginine, were detected only in the sap of L 97-128. A novel approach to evaluate insect resistant and susceptible cultivars is proposed.

Introduction

The Mexican rice borer, Eoreuma loftini (Dyar) (Lepidoptera: Crambidae) and sugarcane aphid, Melanaphis sacchari (Zehntner) (Hemiptera: Aphididae) conform in their herbivore-plant interactions to the plant stress hypothesis (White, 1969). In this relationship, host plants stressed from lack of water, increased salt, reduced soil fertility, or excessive damage are more suitable hosts enhancing one or more aspects of herbivore bionomics (Reay-Jones et al., 2003, 2005b, 2007a). M. sacchari and E. loftini are relatively new pests to Louisiana sugarcane (White et al., 2001, Hummel et al., 2008). In contrast, the more established invasive species, the sugarcane borer, Diatraea saccharalis (F.) conforms to the plant vigour hypothesis where the biology is enhanced by an association with vigorously growing plants (Price, 1991).

Introduced from Mexico into the Lower Rio Grande Valley of Texas in 1980 (Johnson, 1985), E. loftini is the major insect pest of sugarcane representing more than 95% of stalk borer populations in that area (Reay-Jones et al., 2005a). The insect spread northward and north-eastward into Louisiana at a rate of 16.5–23 km/year (Reay-Jones et al., 2007b). E. loftini has been cited as having a potential economic impact on the Louisiana sugarcane industry of up to $220 million/annum (Reay-Jones et al., 2008). Cryptic oviposition sites on dried sugarcane leaves, larval mining of midribs and leaf sheaths, boring into stalks within 3–7 days after egg hatch, and pupation in frass-packed tunnels render E. loftini inaccessible to control by biological and chemical agents (Reay-Jones et al., 2005a).

M. sacchari is the most abundant aphid species in Louisiana sugarcane. It vectors sugarcane yellow leaf virus (SCYLV). SCYLV was discovered in Louisiana in 1999, and in 2002, 48% of
fields were infected throughout the industry (McAllister et al., 2008). Disease management of SCYLV is facilitated using a seed cane certification program conducted by the Louisiana Department of Agriculture and Forestry (McAllister et al., 2008). Spread and incidence of SCYLV depends mainly on the spring migration of *M. sacchari* into the field (McAllister et al., 2005). This indicates potential for using resistant cultivars to prevent disease spread, since these cultivars will presumably attract fewer aphids and/or negatively affect their biology.

The *M. sacchari*-resistant cultivar (HoCP 91-555) and experimental lines with *E. loftini* resistance similar to the commercial resistant HoCP 85-845 demonstrate potential for managing these two invasive pests based on host plant resistance. This paper highlights some of the biochemical relationships involving free amino acids (FAAs) associated with *Saccharum* spp. plant resistance to *E. loftini* and *M. sacchari*.

**Eoreuma loftini**

Screening and finding genetic sources of resistance to *E. loftini* is an important component of the variety development program of the Louisiana State University AgCenter. Commercial and experimental cultivars are evaluated yearly in replicated trials under natural infestations with heavy *E. loftini* pressure at Ganado in Jackson County, TX. Initial studies at this location conducted in 2002 helped identify *E. loftini* susceptible (LCP 85-384) and resistant (HoCP 85-845) cultivars that are used as standards (Table 1). Even though the older cultivar CP 70-321 demonstrated significantly better resistance than HoCP 85-845 under heavy pressure, studies at Weslaco in Hidalgo County with lighter *E. loftini* infestations, showed that HoCP 85-845 would make a better standard (Reay-Jones et al., 2003). Assessing resistance to *E. loftini* requires determination of percentage of bored internodes and per hectare moth production based on frequency of adult (moth) emergence holes (Table 1).

**Table 1**—Injury (+ SEM) by *E. loftini* to six sugarcane cultivars, resultant survival (+ SEM) of older larvae inside the stalks, and moth production (+ SEM) at Ganado, Jackson County, TX, 2002 (Reay-Jones et al., 2003).

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>% Bored internodes</th>
<th>Relative survival a</th>
<th>Moth emergence x10³ /ha b</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCP 85-384</td>
<td>67.5 (5.7)a</td>
<td>0.225 (0.065)a</td>
<td>112.3 (37.5)a</td>
</tr>
<tr>
<td>HoCP 96-540</td>
<td>62.5 (6.8)a</td>
<td>0.200 (0.030)a</td>
<td>105.6 (7.9)a</td>
</tr>
<tr>
<td>HoCP 91-555</td>
<td>57.5 (3.4)ab</td>
<td>0.363 (0.144)a</td>
<td>165.1 (65.4)a</td>
</tr>
<tr>
<td>HoCP 85-845</td>
<td>47.2 (4.9)bc</td>
<td>0.150 (0.039)a</td>
<td>62.7 (17.0)a</td>
</tr>
<tr>
<td>NCo 310</td>
<td>36.2 (3.1)cd</td>
<td>0.166 (0.035)a</td>
<td>53.1 (13.4)a</td>
</tr>
<tr>
<td>CP 70-321</td>
<td>28.3 (1.9)d</td>
<td>0.171 (0.023)a</td>
<td>39.1 (5.5)a</td>
</tr>
<tr>
<td>F c</td>
<td>34.01</td>
<td>1.27</td>
<td>2.12</td>
</tr>
<tr>
<td>P</td>
<td>&lt; 0.0001</td>
<td>0.316</td>
<td>0.106</td>
</tr>
</tbody>
</table>

Means within the same column followed by the same letter are not significantly different (*P* < 0.05; Tukey’s HSD).

a Based on a ratio of *E. loftini* exit holes to bored internodes.
b Estimated as the product of the mean number of exit holes and the number of stalks per hectare. 
c df = 5, 20.

Further studies were conducted to assess nutritional differences between these cultivars using high performance liquid chromatography (HPLC). Whole leaf tissue sample analyses revealed differences in FAA concentrations. As shown in Table 2, the total amount of essential FAAs was more than twice as high in susceptible LCP 85-384 compared with HoCP 85-845.
Table 2—Selected free amino acid (FAA) accumulations (nmol/10 µL juice) in sugarcane leaves (5 node stage) from *E. loftini* susceptible LCP 85-384 and resistant HoCP 85-845, greenhouse oviposition studies at Weslaco, TX 2003-2004 (Reay-Jones et al., 2007a).

<table>
<thead>
<tr>
<th>Free amino acid</th>
<th>HoCP 85-845</th>
<th>LCP 85-384</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arginine</td>
<td>14</td>
<td>31</td>
</tr>
<tr>
<td>Histidine</td>
<td>92</td>
<td>251</td>
</tr>
<tr>
<td>Methionine</td>
<td>0</td>
<td>3.8</td>
</tr>
<tr>
<td>Threonine</td>
<td>42</td>
<td>176</td>
</tr>
<tr>
<td>Valine</td>
<td>56</td>
<td>125</td>
</tr>
<tr>
<td>^Sum</td>
<td>273</td>
<td>612</td>
</tr>
<tr>
<td>^Proline</td>
<td>459</td>
<td>1680</td>
</tr>
<tr>
<td>^Aspartic acid</td>
<td>252</td>
<td>379</td>
</tr>
<tr>
<td>^Serine</td>
<td>177</td>
<td>416</td>
</tr>
</tbody>
</table>

^aTotal of selected ‘essential free amino acids,’ as a necessary component in insect diet, critical for growth and development (Chapman, 1998).

^bNonessential amino acids are not critical for growth but are needed for optimal growth of insect (Chapman, 1998).

These studies also showed a strong ovipositional preference for cultivars and plant conditions which had higher amounts of essential FAAs. Methionine, an essential amino acid was only detected in the leaves of the susceptible LCP 85-384. Ovipositional preference of *E. loftini* indicated positive associations between egg masses per plant and both essential FAAs (arginine, phenylalanine, and threonine) and dry leaves, and between eggs per plant and both essential FAAs (methionine and threonine) and dry leaves (Reay-Jones et al., 2007a). It is also pointed out that this increased nutritional quality is not necessarily limited to just FAAs.

*Melanaphis sacchari*

Greenhouse studies on biotic potential of *M. sacchari* on commonly grown commercial sugarcane cultivars in Louisiana have shown significant cultivar effects on aphid reproductive rates. The cultivar with the least biotic potential (0.06) was HoCP 91-555 compared to the maximum (0.16) on L 97-128, showing greater than 2.6-fold differences in the number of offspring per female per day (Fig. 1).

![Fig. 1—*Melanaphis sacchari* biotic potential on Louisiana sugarcane.](image)

FAAs in the phloem sap indicated that free histidine and arginine were present only in susceptible cultivar L 97-128 (Table 3). The total amount as well as the percentage of essential FAAs in the phloem sap of L 97-128 was also higher when compared to that in the sap of the resistant cultivar HoCP 91-555. In contrast, the phloem sap of HoCP 91-555 was dominated by nonessential FAAs. On-going analyses of honeydew from aphids feeding on both cultivars is
revealing that certain FAAs are detected only in the honeydew of the susceptible cultivar L 97-128 suggesting that the aphid is able to synthesise these FAAs while feeding on this cultivar.

### Table 3—Free amino acid concentrations in the whole leaf tissue (nmole/10 µL juice) and phloem sap (picomole/ µL solution) of the E. loftini and the M. sacchari resistant and susceptible sugarcane cultivars.

<table>
<thead>
<tr>
<th></th>
<th>E. loftini</th>
<th>M. sacchari</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HoCP 85-845 LCP 85-384</td>
<td>HoCP 91-555 L 97-128</td>
</tr>
<tr>
<td>Alanine</td>
<td>447</td>
<td>1442</td>
</tr>
<tr>
<td>Arginine</td>
<td>14</td>
<td>31</td>
</tr>
<tr>
<td>Aspartic acid</td>
<td>252</td>
<td>379</td>
</tr>
<tr>
<td>Glutamic acid</td>
<td>238</td>
<td>96</td>
</tr>
<tr>
<td>Glycine</td>
<td>43</td>
<td>0</td>
</tr>
<tr>
<td>Histidine</td>
<td>92</td>
<td>251</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>Leucine</td>
<td>24</td>
<td>13</td>
</tr>
<tr>
<td>Lysine</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Methionine</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>33</td>
<td>4</td>
</tr>
<tr>
<td>Proline</td>
<td>459</td>
<td>1680</td>
</tr>
<tr>
<td>Serine</td>
<td>177</td>
<td>416</td>
</tr>
<tr>
<td>Threonine</td>
<td>42</td>
<td>176</td>
</tr>
<tr>
<td>Tyrosine</td>
<td>144</td>
<td>18</td>
</tr>
<tr>
<td>Valine</td>
<td>56</td>
<td>125</td>
</tr>
<tr>
<td>Total</td>
<td>2033</td>
<td>4643</td>
</tr>
<tr>
<td>Total essential</td>
<td>273</td>
<td>612.4</td>
</tr>
<tr>
<td>% essential</td>
<td>13.4</td>
<td>13.2</td>
</tr>
<tr>
<td>% nonessential</td>
<td>86.6</td>
<td>86.8</td>
</tr>
</tbody>
</table>

*a*Sum of concentrations of arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, valine.

**Discussion**

Population growth and in turn the pest population on many host plants relates to the plant’s nutritional status, and often the availability of plant FAAs (McNeil and Southwood, 1978; Showler, 2004) in susceptible versus resistant cultivars. Resistant and susceptible cultivars to E. loftini and M. sacchari are showing association with the presence of certain amino acids (Table 3), consistent with the concept that their absence can prevent insect growth (Chapman, 1998). We are finding that some essential amino acids can be synthesised by the sugarcane aphid, and this can help increase their biotic potential on some cultivars lacking those FAAs.

Moths utilise contact chemoreceptors on their antennae, proboscis, tarsi, and ovipositor to assist in completing the behavioural responses essential to accepting or rejecting a host plant (Kogan, 1994). Assuming that E. loftini can detect host plant FAA levels and that such levels influence oviposition preference, levels of essential FAAs may help explain variability in oviposition. E. loftini oviposition was associated with arginine (egg masses per plant) and aspartic acid (eggs laid per plant), which accumulated under water deficit stress (Reay-Jones et al., 2007a). Thus, host plant foliar FAAs likely affected the oviposition preference of E. loftini, a devastating insect pest of sugarcane.

Aphids feed on phloem sap that largely consists of sugars and is limited in nitrogenous compounds. Essential amino acids in the phloem sap are generally less than 25% of the total amino acid concentration with some less than 0.2% (Chapman, 1998). A close association exists between host plant nutritional status including nutrient ratios and development of aphids (Dixon, 1985, Febvay et al., 1988). Our study suggests that the differences in biotic potential on L 97-128 and
HoCP 91-555 are associated with differences in composition and concentration of FAAs detected in the sap.

The preferred feeding site of *M. sacchari* is the lower senescing leaves of sugarcane plants, and one reason for this may be the higher levels of FAAs in these leaves (Reay-Jones *et al.*, 2005b). *E. loftini* prefers to oviposit on senescing leaves of sugarcane that are associated with higher FAAs levels. Therefore, reducing sugarcane drought-stress with irrigation is cited as a way of decreasing *E. loftini* oviposition and possibly *M. sacchari* build up by decreasing both the nutritional value of the crop for these insects and the number of ovipositional sites (i.e., dry leaves) for *E. loftini*. The practical value of these fundamental studies is the potential use of a non-bioassay approach to evaluate resistance and susceptibility of sugarcane cultivars to stalk borers and sap feeders. This would allow screening and selection of insect resistant cultivars in the absence of invasive species, a technique of value in proactive research when the pest has not yet invaded.

**Acknowledgements**

We appreciate critical reviews of Julien Beuzelin, Tim Schowalter, and Gregg Henderson. This research was supported in part by grants from the American Sugar Cane League and the USDA Crops-At-Risk program. This manuscript is approved for publication by the Director of Louisiana Agricultural Experiment Station as ms # 2009-234-3751.

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UNE PERSPECTIVE NUTRITIONNELLE DE LA RESISTANCE DE LA CANNE À SUCRE AUX FOREURS DES TIGES ET AUX INSECTES PIQUEURS-SUCEURS

Par
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MOTS CLES: Eoreuma loftini, Melanaphis sacchari, Saccharum spp., Acides Aminés Libres, Cultivar Résistant.

Résumé
Parmi les principaux insectes ravageurs attaquant la canne à sucre en Louisiane, le foreur des tiges Eoreuma loftini (Dyar) et le puceron Melanaphis sacchari (Zehntner) se comportent similairement dans leurs interactions avec leur plante hôte. Ces deux insectes suivent la « plant stress hypothesis », hypothèse selon laquelle un herbivore préférerait une plante stressée. La technique de chromatographie liquide à haute performance a été utilisée pour différencier les cultivars résistants et sensibles à ces insectes en se basant sur les profils des acides aminés libres (AAL) présents. Dans le cultivar sensible a E. loftini, LCP 85-384, les concentrations en AAL essentiels et non-essentiels étaient plus du double de celles mesurées dans le cultivar résistant, HoCP 85-384. De même, L 97-128, un cultivar sensible a M. sacchari, avait des concentrations en AAL essentiels plus de trois fois supérieures a celles mesurées dans la sève élaborée du cultivar résistant HoCP 91-555. Deux AAL essentiels, l’histidine et l’arginine, n’ont été détectés que dans la sève de L 97-128. A partir de ces résultats, la possibilité d’une approche évaluant la résistance des cultivars de canne à sucre à certains ravageurs sans recourir à des infestations d’insectes est discutée.
UNA PERSPECTIVA NUTRICIONAL DE LA RESISTENCIA DE LA CAÑA DE AZUCAR A BARRENADORES DEL TALLO Y CHUPADORES

Por

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PALABRAS CLAVE: Eoreuma loftini, Melanaphis sacchari, Saccharum spp., Amino Acidos Libres, Cultivos Resistentes.

Resumen

DOS PLAGAS relativamente nuevas, el barrenador mexicano del arroz, Eoreuma loftini (Dyar) y el áfido gris de la caña de azúcar, Melanaphis sacchari (Zehntner), son claves en Luisiana para probar la hipótesis del estresamiento de la planta. A través de la técnica de la cromatografía líquida de alta eficacia, se pudo diferenciar cultivares de caña de azúcar resistentes y susceptibles al ataque de insectos, basados en perfiles nutricionales que involucran amino ácidos libres (FAAs). Para el cultivar LCP 85-384 susceptible a E. loftini, las concentraciones de los FAAs esenciales y no esenciales en las muestras de todo el tejido de la hoja fueron superiores en más de dos veces que las encontradas en el cultivar resistente HoCP 85-845. Similarmente, L 97-128 susceptible a M. sacchari presentó concentraciones tres veces más altas de FAAs en la savia del floema al compararlo con el cultivar resistente, HoCP 91-555. Dos FAAs esenciales, histidina y arginina, se detectaron solo en la savia de L 97-128. Se propone este enfoque novedoso para evaluar cultivares resistentes y susceptibles.
VECTOR-VIRUS RELATIONSHIP FOR MELANAPHIS SACCHARI (ZEHNT.) (HEMIPTERA: APHIDIDAE) TRANSMITTING SUGARCANE YELLOW LEAF LUTEOVIRUS IN MAURITIUS

By

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KEYWORDS: Melanaphis sacchari, Acquisition, Transmission, Yellow Leaf.

Abstract

SUGARCANE yellow leaf virus (ScYLV) was reported in Mauritius in 1995. It spreads by vegetative propagation and is transmitted to healthy plants by the aphid, Melanaphis sacchari (Zehnt.) that prevails at a very low density in commercial plantations. The relationships pertaining to the vector and the luteovirus were investigated under laboratory conditions, as an understanding of the acquisition and transmission of the virus by the vector is a prerequisite for further studies on the epidemiology, economic importance and management of the disease at field level. An appropriate aphid rearing technique was developed so as to establish cultures of infected and healthy aphids for the relevant studies. To determine the acquisition time of the virus by aphids, infected plants of the sugarcane variety M 695/69 were infested with non-viruliferous aphids which were sampled daily over 4 consecutive days and tested by RT-PCR. M. sacchari acquired the virus within 24 h and more precise tests in the insectary, whereby aphids were sampled every 30 min over 6 h, indicated that the virus was acquired after 4.5 h of feeding on infected plants. The time taken for the viruliferous aphids to transmit the virus to disease-free tissue cultured plantlets was determined by allowing infected aphids from the breeding cages to feed on the plantlets for periods of 2, 8, 17 and 28 days. The virus was transmitted to healthy plants within 2 days. This is the first record of M. sacchari being a vector of ScYLV in Mauritius and the present laboratory data provide basic information for future field experimentation and research work on vector-virus interactions.

Introduction

Yellow leaf (previously referred to as yellow leaf syndrome) was first reported in Hawaii in 1988. The disease, which is now widespread across the world, is caused by Sugarcane yellow leaf virus (ScYLV), a Polerovirus of the Luteoviridae family (D’Arcy and Domier, 2005) which also contains barley dwarf virus, soybean dwarf virus, potato leaf roll virus and pea mosaic virus (Comstock and Gilbert, 2008). ScYLV is limited to the phloem tissue and is spread mainly by vegetative propagation through infected cuttings and transmitted to healthy plants by aphids (Rassaby et al., 2004; Comstock and Gilbert, 2008). The aphid species proven to transmit the virus are the sugarcane aphid, Melanaphis sacchari (Zehntner), the corn leaf aphid Rhopalosiphum maidis (Fitch) and the rice root aphid, R. rufiabdominalis (Sasaki). The former species is a vector of three persistent viruses, namely millet red leaf, sugarcane yellow leaf and sugarcane mosaic viruses (Singh et al., 2004). Not all aphid species infesting sugarcane are vectors of ScYLV (Schenck and Lehrer, 2000).

The disease was reported in Mauritius in 1994 but its epidemiology and the effect on yield were not clear. Symptoms were subsequently observed in several commercial varieties (Saumtally and Moutia, 1997), although the aphid population in commercial plantations is low. This paper
describes the incidence of the vector in the fields and studies in the insectary relating to the establishment of cultures of healthy and infected aphids, the determination of the acquisition time of the virus by aphids and the transmission of the disease to healthy plants. These studies will give a better understanding of the relationships pertaining to the vector and the virus. Data from these investigations may help to implement appropriate measures for timely provision of infected aphids for future studies on yield assessments of different varieties and the rate of transmission and ScYLV dissemination in the field with respect to the different genotypes detected locally.

**Materials and methods**

**Incidence of aphids**

To assess the potential of early infection in the epidemiology of the disease, surveys were initially conducted in transplanted seedling plantations set on four experimental stations located in the subhumid, humid and superhumid zones of Mauritius. Potted seedlings in the shadehouses at Réduit (humid region) were also surveyed.

Field surveys were then conducted to identify the aphid species, their distribution and their incidence in the various agroclimatic zones of the island. Surveys were carried out in commercial plantations and varietal preference was recorded. Leaf samples and aphids, if any, were collected at 25 points selected at random in each field. All aphids were kept in 70% alcohol and tested for whether they were viruliferous according to the method of Rassaby *et al.* (2004). To allow correlations to be made between the virus incidence and the vector population, the leaf samples were tested by tissue blot immunoassays (TBIA) using a cross-absorbed polyclonal antibody and the technique developed by Schenck *et al.* (1997). Confirmatory tests were effected with the leaf samples by reverse transcription polymerase chain reaction (RT-PCR) (Joomun and Dookun-Sauntally, 2008; Khoodoo *et al.*, 2008; MSIRI, 2008b).

**Insect rearing**

An investigation was carried out in the insectary to determine the most appropriate rearing method for *M. sacchari*. Young potted maize plants, potted sugarcane plants, cut leaves and cut shoots in water were infested with aphids in wooden cages (45 cm x 45 cm x 118 cm) and observations on insect development were recorded weekly over at least two generations.

**Acquisition tests**

Acquisition tests were conducted to determine whether *M. sacchari* is a potential vector of the ScYLV under controlled conditions in the insectary. Virus-free aphids, which were collected from healthy seedlings, were reared in three wooden insect cages (30 aphids/cage) each containing two cut shoots of infected plants of cane variety M 695/69 in water. After about two weeks, a random sample of five aphids was collected from each of these cages and tested for the presence of the ScYLV in single aphids by RT-PCR (MSIRI, 2008b). Positive results on the potential of *M. sacchari* as a vector of ScYLV then led to the establishment of additional tests to determine the time taken for the vector to acquire and transmit the virus.

About thirty virus-free aphids were collected from seedlings at Réduit and placed in contact with infected shoots of M 695/69 in wooden cages as described above. In addition to the three replicate cages with infected shoots, a control batch was also set with disease-free plantlets of variety R 570. Five aphids were removed from each of the four cages after 24, 48, 72 and 96 hours and kept in 70% alcohol for the detection of the virus.

Further tests were conducted to determine more precisely the acquisition time within 24 hours. One infected shoot of M 695/69 was placed in a conical flask containing water and was artificially infested with about eighty virus-free aphids collected from the seedlings. Three replicate flasks were set up and a control using disease-free plantlets of variety R 570 was also established. Five aphids were removed from each replicate flask every 30 minutes from 10 am for 5 ½ hours and kept in alcohol for virus detection.
Transmission tests

To determine whether infected aphids would transmit the virus to healthy plants, infected aphids from the breeding cages were placed in contact with three disease-free plantlets of R 570 in each wooden cage for different time periods of 2, 8, 17 and 28 days. All aphids from each of the cages were killed after the respective time periods by foliar application and soil drenching with thiamethoxam (Actara 25 WG) at 0.0625 g a.i./L. Samples of five aphids were taken at random from each plant in each cage to ascertain their infective nature. All the plants were subsequently transferred to insect-proof cages; after 45 days, leaves were sampled randomly from all the cages for the detection of the ScYLV by TBIA.

Results

Incidence of aphids

Results from the field surveys showed that the population of aphids in transplanted seedlings on three of the experimental stations was much lower than that at Réduit situated in the humid region. Surveys in the seed beds at Réduit indicated a high infestation and several colonies of about twenty aphids per leaf were sometimes encountered on the small plants despite the weekly cutting back prior to their transplantation to the commercial plantations. No ScYLV infection was detected in the leaves or aphids at the seedling stage on the four experimental stations.

Surveys in the commercial plantations showed that the only recorded aphid species was *M. sacchari* while the other potential vector, *R. maidis*, was not recorded. The population of *M. sacchari* was low island-wide, being prevalent in about 10% of the fields which were visited, except in one field at Savannah where hundreds of aphids comprising all stages were recorded on a few leaves in association with the soft scale, *Pulvinaria iceryi* Sign.

Insect rearing

*M. sacchari* could be successfully reared for 2–3 generations on young cut shoots of M 695/69 kept in water and this breeding method was adopted throughout the studies. Both apterous and alate forms of *M. sacchari* developed in large numbers (approximately 100–200 aphids per shoot) in the breeding cages. Young maize plants, cut sugarcane leaves and young potted plants were not appropriate for breeding aphids for several generations in the insectary.

Acquisition and transmission tests

Healthy aphids collected from seedlings multiplied rapidly on the infected leaves of cane variety M 695/69 in the insectary. After about four days, leaves showed pronounced yellowing and in about three weeks, a very high population of alate and apterous aphids was observed in all three cages. These aphids were found to be infected with ScYLV while aphids from the control cage tested negative. Laboratory tests clearly demonstrated that *M. sacchari* is a potential vector of ScYLV. Acquisition tests showed that the vector could acquire the virus within 24 hours as reported in the literature and more precise laboratory tests indicated that the virus was acquired after 4.5 hours in two replicate flasks (MSIRI, 2008a).

Tests on the aphids prior to the transmission studies confirmed their infective nature. Investigations on the transmission of the virus in the insectary at Réduit showed that the virus could be transmitted by viruliferous aphids to healthy plantlets of cane variety R 570 within two days (MSIRI, 2008a). All the leaf samples, except those sampled from plants that were exposed for a period of eight days, were found to be infected.

Discussions and conclusions

Field surveys in Mauritius have provided useful information on the epidemiology of ScYLV for the subsequent implementation of appropriate measures for its management and for future studies. The only aphid species that was found to be associated with the disease was *M. sacchari*. Similar investigation of infestation and transmission efficiency reported in the literature showed that *M. sacchari* was the only vector important for the field spread of the disease in Hawaii (Lehrer *et*
of $M. \text{sacchari}$ was limited and its population in the commercial plantations was low as colonies were detected in very few localities.

This contrasts with the situation in Guadeloupe where $M. \text{sacchari}$ is widespread in all areas and ScYLV appears to be spread by aphid vectors and infected cuttings (Edon-Jock et al., 2007). However, in Louisiana, the incidence and rate of disease increase remained low despite the widespread occurrence of the potential vectors (McAllister et al., 2008) which have a low rate of dispersal (Lehrer et al., 2007). In Mauritius, the widespread and high incidence of the virus in commercial varieties, the absence of infected aphids in transplanted seedlings and the low vector population in commercial fields indicate that the main source of infection is through the vegetative propagation of infected cane settts as reported by Khoodoo et al. (2008). This is despite the fact that our studies highlighted the short time needed for the vector to acquire and transmit the virus.

In this present study, the aphids were killed in alcohol right after removing them from the infected plants. The acquisition time might have been shorter if the aphids were left on healthy plants for some time to allow the virus to multiply in the aphids.

These observations in Mauritius correlate well with previous studies carried out by Edon-Jock et al. (2007) in Guadeloupe, where virus incidence was consistently high in R 579 even though colonisation by aphids was low. Similarly, no indication of long-distance transfer via aphids could be seen in Hawaii, indicating that it may be possible to produce and use virus-free seed cane for planting of high-yielding but susceptible cultivars (Lehrer et al., 2007).

Aphid control using insecticides as proposed in the literature should be adopted judiciously. In Mauritius, this practice is not warranted due to the low vector population and because established biological control of major sugarcane pests through a complex of predators and parasitoids may be disrupted by insecticide use.

In countries where control of the vector population is necessary, biological control of the main vector species, $M. \text{sacchari}$, integrated within a varietal development program may be attempted as revealed by the high potential of the coccinellid predator, $Diomus \text{terminatus}$ Say, in adult voracity tests in Louisiana (Akbar et al., 2009; Akbar and Reagan, 2006).

The present study highlighted the fact that initial contamination occurs in the field probably by aphid vectors and subsequently settts issuing from infected fields help in the transmission of the disease. The short acquisition and transmission time by the vector is definitely of concern, especially as four different genotypes have been detected so far as revealed by genetic diversity studies (Joomun and Dookun-Saumtally, 2008; MSIRI, 2008b).

As genotypes vary in their virulence, future studies can be carried out to determine whether there is a differential pattern in the transmission and acquisition of the different biotypes of the virus by $M. \text{sacchari}$. Additionally, the information obtained on transmission and acquisition will be useful to obtain infected plants for field experimentation, using $\text{in vitro}$ plantlets as initial starting material.

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RELATION VECTEUR-VIRUS DE *MELANAPHIS SACCHARI* (ZEHNT.)
(HOMOPTÈRE: COCCIDE), VECTEUR DU VIRUS DE LA FEUILLE JAUNE DE LA CANNE À SUCRE

Par

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Résumé

La maladie de la feuille jaune de la canne à sucre a été répertoriée à Maurice en 1995. Le virus (*Sugarcane yellow leaf virus* – ScYLV) est propagé par boutures infectées et est transmis par le puceron *Melanaphis sacchari* (Zehnt.) présent à faible densité dans les plantations commerciales. Des études ont été effectuées au laboratoire sur la relation virus-vecteur, car des données sur l’acquisition et la transmission du virus sont nécessaires pour déterminer l’épidémiologie, l’impact économique et la gestion de la maladie. Une méthode fut établie pour l’élevage en masse de pucerons infectés et sains. L’acquisition du virus fut déterminée en exposant les pucerons sains à des plantes infectées de la variété M 695/69. Des échantillons de pucerons ont été prélevés chaque jour sur une période de quatre jours et analysés par RT-PCR. Les résultats démontrent que le virus est acquis dans les 24 heures et des essais plus précis, en prélevant des pucerons chaque trente minutes sur une période de six heures indiquent que le vecteur peut acquérir le virus après avoir été exposé pendant 4.5 heures aux plantes infectées. Le temps requis pour la transmission du virus par le vecteur à été évalué en exposant les pucerons infectés aux plantules *in vitro* pour une période de 2, 8, 17 et 28 jours. Le virus était transmis aux plantules en 2 jours. L’étude démontre que *M. sacchari* est un vecteur du ScYLV et les données préliminaires obtenues seront importantes pour des études plus approfondies au champ.
RELACIONES VECTOR-VIRUS PARA MELANAPHIS SACCHARI (ZEHNT.)
(HEMIPTERA: APHIDIDAE) TRANSMISOR DEL VIRUS AMARILLO DE LA HOJA
LUTEOVIRUS EN MAURICIO

Por

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Palabras clave: Melanaphis sacchari, Adquisición, Transmisión, Hoja Amarilla.

Resumen
El virus de la hoja amarilla de la caña de azúcar (ScYLV) se registró en Mauricio en 1995. El virus se dispersa por propagación vegetativa y se transmite a plantas sanas por el áfido, Melanaphis sacchari (Zehnt.) que prevalece en poblaciones muy bajas en plantaciones comerciales. Las relaciones que tienen que ver con el vector y el luteovirus se investigaron bajo condiciones de laboratorio, ya que entender el proceso de adquisición y transmisión del virus por el vector, es un prerrequisito para posteriores estudios sobre la epidemiología, importancia económica y manejo de la enfermedad a nivel del campo. Se desarrolló una metodología apropiada de cría del áfido para establecer cultivos de áfidos infectados y sanos para los estudios pertinentes. Para determinar el tiempo de adquisición del virus por los áfidos, se infestaron con áfidos no virulentos, plantas infectadas con el virus de la variedad de caña de azúcar M 695/69. Los áfidos se muestearon diariamente durante 4 días consecutivos y se probaron por RT-PCR. M. sacchari adquirió el virus en 24 h y ensayos más precisos en el insectario, donde los áfidos se muestrearon cada 30 min durante 6 h, indicaron que el virus se adquirió después de 4.5 h de alimentarse en plantas infectadas. El tiempo que toma a los áfidos virulíferos para transmitir el virus en tejido libre de virus de plántulas se determinó permitiendo a los áfidos infectados de las jaulas de cría alimentarse de las plántulas por periodos de 2, 8, 17 y 28 días. El virus se transmitió a plantas sanas en 2 días. Este es el primer registro de M. sacchari como vector de ScYLV in Mauritio y los datos de laboratorio de este estudio proveen información básica para futuras investigaciones de campo y trabajos sobre interacciones entre vector y virus.
EFFECTS OF FIPRONIL BAIT ON SUGARCANE YIELD IN OKINAWA, JAPAN

By
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KEYWORDS: Fipronil Bait, Phytostimulatory, Sorghum, Sugarcane Yield, Wireworm.

Abstract
FIPRONIL bait (Prince® Bait, BASF Agro), newly registered as a sugarcane insecticide in 2006 in Japan, has been shown to reduce sugarcane wireworm, Melanotus sakishimensis and M. okinawawesis (Coleoptera: Elateridae), damage and increase sugarcane yield. In January 2008, a high sugarcane growth rate was observed in fipronil bait-treated areas in Minami-daitou Island. To confirm this high growth rate, we investigated sugarcane growth and yield in two fields on Minami-daitou Island from March to December 2008. Moreover, as we suspected that fipronil has a phytostimulatory effect that promotes sugarcane growth, we conducted a simple test using sorghum, also a gramineous C4 crop and a species with a high degree of collinearity with sugarcane. Research on Minami-daitou Island showed that sugarcane growth in the fipronil bait-treated area was significantly higher than the areas treated with ethylthiodemeton granule insecticide (TD®, Sankyou Agro) or isoxathion granule insecticide (TD® Ace, Sankyou Agro). Further, cane yield in the fipronil bait-treated area was also significantly increased as compared with that in the ethylthiodemeton granule and isoxathion granule insecticide-treated areas. Sorghum tests showed that the coleoptile length of sorghum seeds increased when treated with 0 to 10 ppm of fipronil, and then decreased for concentrations over 10 ppm. It was concluded that fipronil bait treatment in sugarcane fields can significantly increase both the growth and yield of sugarcane. Moreover, it was suggested that fipronil at low concentrations may have a phytostimulatory effect on sorghum seedlings.

Introduction
Fipronil (5-amino-1-[2,6-dichloro-4-(trifluoromethyl) phenyl]-4-[(trifluoromethyl)sulfinyl]-1H-pyrazole-3-carbonitrile) is a phenylpyrazole insecticide that interferes with GABA (γ-aminobutyric acid)-gated ion channels (Figure 1).

It blocks chloride ions influx by acting on GABA-gated chloride ion channels, and causes excessive neural excitation, paralysis, and eventual death (Gunasekara et al., 2007). Since registration in 1996, fipronil has been widely used in many cropping systems around the world, including Japan, particularly in rice production.

In 2006, fipronil bait insecticide (0.5% active ingredient, Prince® Bait, BASF Agro) for sugarcane was registered in Japan. The formulation consists of only 0.5% fipronil and approximately 99.5% grain-based material, and differs from conventional sugarcane insecticides in its mode of action.

This insecticide attracts insects with the grain-based material, which leads to the uptake of fipronil by the insect. In addition, fipronil has systemic activity and can control insects such as boll weevils, rootworm and wireworm (Clive, 2006). Sugarcane wireworm, Melanotus sakishimensis and M. okinawawesis (Coleoptera: Elateridae), is a serious economic pest in Japan (Nagamine and Kinjo, 1979).
Tarora et al. (2007) demonstrated that Prince® Bait has an attractant effect and causes high wireworm mortality in laboratory tests. Moreover, the number of ratoon shoots was significantly higher in bait-treated fields than in fields treated with carbosulfan granule insecticide, a conventional insecticide used against wireworm in Japan, on Miyako Island.

However, their research differs from our research in terms of location, insecticide standard and planting season. They studied wireworm damage in three crops: summer planting, spring planting and ratooning, but the yield research was performed only at spring planting.

As no fipronil insecticides for sugarcane were available in Japan before 2006, there are few reports on the effects of fipronil bait insecticide on sugarcane yield.

The present study was aimed at demonstrating the effects of this bait insecticide on sugarcane yield on Minami-daitou Island, its impact on pest insects, as well as its phytostimulatory effects.

\[ \text{Chemical structure of fipronil.} \]

**Materials and methods**

**Research on Minami-daitou Island**

The research was conducted in two fields, A (1.3 ha) and B (1.6 ha), planted with *Saccharum* spp. cv. Ni26 on Minami-daitou Island in Okinawa.

Fields A and B were treated with fipronil bait, while the control areas in each field were treated with ethylthiodemeton granule insecticide (3.0% a.i., TD®, Sankyou Agro) and isoxathion granule insecticide (2.0% a.i., TD® Ace, Sankyou Agro), respectively.

Ethylthiodemeton insecticide and isoxathion granule insecticide are both conventional insecticides used against wireworms in Okinawa. Field studies were conducted on March 21–22, April 12–13, July 12–13, October 8–9, and December 20–21, 2008.

From March 21–22 to October 8–9, growth analysis was conducted. Briefly, 3 blocks were selected in each insecticide-treated area, and the sub-stem length of the main stem, number of tillers and number of dead heart stalks per block were measured. In addition, the number of stalks was determined for an area of 7.0 × 1.5 m. Sub-stem length was defined as the length to the dewlap of the first leaf.

Data on the number of tillers, stalks and dead heart stalks were not recorded on October 8–9 in field A due to severe lodging. Yield sampling was conducted on December 20–21. A 2.2 × 1.5 m plot was cut in each insecticide-treated area, and the diameter of each stem, sub-stem length, and number of stalks per plot was measured.

The crown above the dewlap of the 5th leaf was pruned off, and the length and weight of each stem was measured. Sugarcane yield per 10 a was calculated from the number of stalks per 2.2 × 1.5 m plot and stem weight data. To evaluate sugarcane quality, sucrose content was analysed from 5 juice samples per plot using an HPLC system (LC-10A, Shimadzu). The data for each field were analysed using Student’s t-test, with a value <0.05 considered as significantly different.
Phytostimulatory effect

Sorghum seeds (Sorghum bicolor cv. FS501) were used to assess potential phytostimulatory effects because sorghum has the same photosynthetic process as sugarcane and a high degree of collinearity exists between the two crops. Adjustment of the fipronil concentration was difficult as it has low water solubility. A suspension concentrate (SC) (5.0% a.i., Prince® Flowers, BASF Agro) was therefore used for the laboratory experiments. A 5.0% (50 000 ppm) fipronil SC was diluted to produce 10 concentrations (0, 1, 2.5, 5, 7.5, 10, 25, 50, 75, 100 ppm) in distilled water. A total of 10 seeds per treatment were placed in a vial (50 mL), and 50 mL of each fipronil concentration was added. All vials were capped and left to incubate for 2 h.

Seed samples (one seed per tube) and solutions (4 mL per tube) were then transferred to a liquid-filter paper culture medium in glass tubes. All tubes were covered by parafilm and maintained in the dark for 4 days at 30°C. Germination rate, rooting rate, coleoptile length and root length were measured.

Germination and rooting were considered to have occurred if the coleoptile and root were more than 1 mm in length. The experiment was replicated three times and means compared by Scheffe’s test at p<0.05.

Results

Research on Minami-daitou Island

Figures 2 and 3 show sugarcane growth from March to October, 2008, and Figures 4 and 5 are photos taken in March, 2008. In field A, sub-stem length in the fipronil-bait treated area was significantly longer than that in the ethylthiodemeton insecticide-treated area in March and April. In field B, sub-stem length in the fipronil-bait treated area was also significantly longer than that in the isoxathion-treated area in March, April and October.

The number of stalks peaked in March in all areas, except in the isoxathion-treated plots where it peaked in April, and decreased thereafter. This decrease was due to the death of non-productive tillers through competition.

Although the number of tillers peaked in April and thereafter decreased in all plots, no significant differences were detected between the fipronil bait- and conventional insecticide-treated plots.

The number of dead heart stalks in the fipronil bait-treated plots was lower than in the conventional insecticide-treated plots in March, April and October, but this difference was not apparent in July.

Table 1 shows the yield sampling results for December 2008. In the fipronil bait-treated plots, stem length and sub-stem length in field A, and stem length, diameter and weight in field-B were significantly higher than the values obtained in the conventional insecticide-treated plots.

<table>
<thead>
<tr>
<th>Field</th>
<th>Treatment</th>
<th>No. of stalks* (2.2×1.5m)</th>
<th>Stem length (cm)</th>
<th>Sub-stem length (cm)</th>
<th>Stem diameter (mm)</th>
<th>Stem weight (kg)</th>
<th>Sucrose %</th>
<th>Yield 10a-1 (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Fipronil</td>
<td>32</td>
<td>336.5 ± 84.8*</td>
<td>379.5 ± 98.1*</td>
<td>31.05 ± 3.56</td>
<td>1.59 ± 0.57</td>
<td>16.4 ± 3.5</td>
<td>15.45</td>
</tr>
<tr>
<td></td>
<td>Ethylthiodemeton</td>
<td>20</td>
<td>292.5± 59.8</td>
<td>339.2± 69.6</td>
<td>30.88± 5.59</td>
<td>1.44 ± 0.60</td>
<td>18.2± 1.5</td>
<td>8.53</td>
</tr>
<tr>
<td>B</td>
<td>Fipronil</td>
<td>31</td>
<td>296.0± 44.2*</td>
<td>337.1 ± 49.1</td>
<td>32.81 ± 3.13*</td>
<td>1.51± 0.46</td>
<td>18.7± 1.4</td>
<td>13.96</td>
</tr>
<tr>
<td></td>
<td>Isoxathion</td>
<td>29</td>
<td>275.2±46.6</td>
<td>320.7±62.3</td>
<td>29.69±4.41</td>
<td>1.27±0.46</td>
<td>19.3±0.9</td>
<td>11.19</td>
</tr>
</tbody>
</table>

*p<0.05.

There were no significant differences in sucrose content between fipronil treatments. These results show that fipronil bait treatment improved sugarcane growth and yield without reducing cane juice quality.
Fig. 2—Effects of fipronil bait treatments on the number of stalks and sub-stem length. Bar and line graphs show sub-stem length and number of stalks per 10 a, respectively. *P<0.05, **P<0.01.

Fig. 3—Effects of fipronil bait treatments on the number of tillers and damaged stalks. Bar and line graphs show tiller number per block and number of damaged stalks per block, respectively.
Phytostimulatory effect

Figures 6 and 7 show the effects of fipronil on coleoptile (upper) and root (lower) length in sorghum, respectively, and Table 2 shows the results of germination and rooting rates.

From these results, no significant differences were observed between treatment concentrations.

However, there was a tendency for coleoptile length to gradually increase from 0 to 10 ppm, and then to decrease again over 10 ppm. Germination and rooting rates were 85 to 100% regardless of concentration.

These results show that fipronil, at a low concentration of 10 ppm, enhanced sorghum growth.
Fig. 6—Effects of fipronil on sorghum coleoptile and root length. The thin lines in the figures show coleoptile (thin red line) and root (thin blue line) length at 0 ppm.

Table 2—Effects of fipronil on the germination and rooting rates of sorghum seeds.

<table>
<thead>
<tr>
<th>Concentration (ppm)</th>
<th>0</th>
<th>1</th>
<th>2.5</th>
<th>5</th>
<th>7.5</th>
<th>10</th>
<th>25</th>
<th>75</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germination (%)</td>
<td>95</td>
<td>95</td>
<td>95</td>
<td>90</td>
<td>100</td>
<td>95</td>
<td>85</td>
<td>95</td>
<td>95</td>
</tr>
<tr>
<td>Rooting (%)</td>
<td>100</td>
<td>95</td>
<td>95</td>
<td>85</td>
<td>100</td>
<td>95</td>
<td>85</td>
<td>95</td>
<td>95</td>
</tr>
</tbody>
</table>

Discussion

The sugarcane wireworm has caused substantial damage for a number of years to sugarcane production in Okinawa. Wireworms damage sugarcane shoots, stems and roots, and shoots are especially damaged as compared with other plant parts. Therefore, non-germination, dead heart, non-ratooning are caused, and sugarcane yield decreases in damaged field (Oshiro et al., 2006). In the 1960s, the incidence of wireworm decreased due to the use of organic chlorine insecticides; however, the subsequent ban of this type of insecticide led to an increase in wireworm numbers after 1971 (Azuma, 1977). Sugarcane production, therefore, decreased as wireworms damage ratoon shoots, and the ratoon crops do not grow as well in damaged fields. At
the same time, labour costs increased, leading to lower profitability. Therefore, a strong demand existed for a new insecticide to prevent wireworm damage in ratoon fields.

In the present study, research was conducted on Minami-daitou Island, one of the areas of large-scale sugarcane production in Okinawa. Sugarcane growth and yield were found to be significantly increased in the fipronil bait-treated areas compared with the control area in each field studied. Early growth (6 months after planting) was increased substantially by the use of fipronil. Nagamine and Kinjo (1979) showed that wireworm damage was confirmed in the early growth stages until three months after planting, especially within the first month (personal communication). In our study, we did not detect any wireworm damage up to 6 months after planting. Future research will focus on sampling for damage earlier in the season.

Although ethylthiodemeton insecticide has been used for a long time to control wireworms in Minami-daitou Island, it was found to be not as effective in controlling wireworms as the fipronil bait. The results suggest that wireworms may have developed resistance to this insecticide on Minami-daitou Island. Future research will also focus on this resistance of wireworm.

From the present study, we speculate that the increase in growth and yield in the fipronil-treated sugarcane was caused by factors other than the reduction in wireworm-related damage. It is already known that 3-cyano-1-phenylpyrazoles, such as fipronil, regulate and promote plant growth. Therefore, we hypothesised that fipronil has a phytostimulatory effect that promoted sugarcane growth, and developed a simple test using sorghum, which has the same type of photosynthetic process as sugarcane. Although there were no significant differences, 10 ppm of fipronil led to a slight increase in the length of the coleoptile of sorghum seedlings. Stevens et al. (1999) showed that 2000 mg/L fipronil inhibited the early growth of rice. Though they examined higher fipronil concentrations (250–4000 mg/L), Garcia del Pino and Jove (2005) also showed that the optimum field rate for fipronil was 12–60 ppm, and suggested that the same concentration of fipronil should be used in sugarcane fields. These results show that fipronil at low concentrations of about 10 ppm can increase plant growth, whereas high concentrations of about 2000 ppm can inhibit plant growth. Moreover, Clive (2006) indicated that the application of fipronil as an incorporated soil treatment to cotton, maize, sugar beet or sunflower leads to limited uptake of fipronil into plants. However, it is not known about penetration of fipronil into sugarcane. Further study is required to clarify the uptake of fipronil into sugarcane and the phytostimulatory effect of fipronil on sugarcane.

The present study showed that fipronil bait treatment increases sugarcane growth and yield as compared with conventional insecticides on Minami-daitou Island; therefore, fipronil bait can be regarded as a promising insecticide for use in sugarcane production. However, further research is necessary to better quantify the systemic activity of fipronil in sugarcane as well as its phytostimulatory effect on growth.

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EFFETS D'UN APPAT À BASE DE FIPRONIL SUR LE RENDEMENT DE LA CANNE À SUCRE À OKINAWA, JAPON

Par

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MOTSCLÉS: Appât au Fipronil, Phytostimulateurs, Sorgho, Rendement De Canne, Taupin.

Résumé

Un appât à base de fipronil (Prince®, Bait, BASF Agro), nouvellement homologué comme insecticide pour la culture de la canne à sucre en 2006 au Japon, a réduit efficacement les dégâts du taupin, Melanotus sakishimensis et M. okinawawesis (Coleoptera: Elateridae), tout en augmentant le rendement. En janvier 2008, une croissance élevée de la canne à sucre a été observée dans les régions traitées à l’appât sur l’île Minami-daitou. Afin de confirmer cette forte croissance, nous avons étudié la pousse de la canne et le rendement dans deux champs sur l’île de mars à décembre 2008. De même, comme nous soupçonnions que le fipronil avait des propriétés phytostimulatrices permettant de promouvoir la croissance de la canne à sucre, nous avons effectué un test simple en utilisant le sorgho, une graminée à fort degré de parenté avec la canne à sucre et une plante C₄. La recherche sur l’île Minami-daitou a démontré que la croissance était significativement plus élevée dans les régions traitées à l’appât au fipronil comparée aux régions traitées à l’insecticide éthylthiodémeton (TD®, Sankyou Agro) ou isoxathion (TD® Ace, Sankyou Agro) en formulation granulée. De plus, le rendement en canne dans les régions traitées au fipronil était significativement supérieur comparé aux traitements d’éthylthiodémeton et d’isoxathion. La longueur du coléoptile des graines de sorgho était supérieure avec un traitement de 0 à 10 ppm de fipronil par rapport à des concentrations de plus de 10 ppm où une diminution a été constatée. Il est conclu que l’appât à base de fipronil pourrait accroître le rendement ainsi que la croissance de la canne de manière significative. De plus, il semblerait qu’une faible concentration de fipronil ait un effet phytostimulateur sur les plantules de sorgho.
EFECTOS DEL CEBO FIPRONIL EN LA PRODUCCIÓN DE CAÑA DE AZÚCAR EN OKINAWA, JAPÓN

Par

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PALABRAS CLAVE: Cebo Fipronil, Fitoestimulatorio, Sorgo, Rendimiento Caña de Azúcar, Gusano Alambre.

Resumen

EL CEBO Fipronil (Prince Bait, BASF Agro), recientemente registrado en 2006 como un insecticida para la caña de azúcar en Japón, se encontró que reduce el daño causado por los gusanos alambres Melanotus sakishimensis y M. okinawawesis (Coleoptera: Elateridae) y a su vez puede aumentar la producción de la caña de azúcar. En enero de 2008, se observó una alta tasa de crecimiento de las cañas tratadas con cebo Fipronil en la isla de Minami-daitou. La confirmación del aumento en la tasa de crecimiento y su producción, se investigó en dos campos en la isla de Minami-diatou entre marzo y diciembre de 2008. Más aún, debido a que se sospechaba que el Fipronil, tiene un efecto fitoestimulador al promover el crecimiento de la caña de azúcar, se condujo una prueba sencilla usando sorgo, también un cultivo de una especie de graminea C₄, especie que tiene un alto grado de colinearidad con la caña de azúcar. La investigación se realizó en la isla de Minami-daitou y demostró que el crecimiento de la caña de azúcar en las áreas tratadas con el cebo Fipronil fue significativamente más alto que en las áreas tratadas con el insecticida granulado etiltiodemeton (TD, Sankyou Agro) o el insecticida granulado isofoxation (TD Ace, Sankyou Agro). Además, la producción de caña de las áreas tratadas con el cebo Fipronil también fue significativamente superior al de las áreas tratadas con los insecticidas granulados etiltiodemeton e isofoxation. Las pruebas con sorgo mostraron que la longitud del coleóptilo de las semillas de sorgo aumentó cuando se trataron con 0 a 10 ppm de Fipronil y luego disminuyeron en las concentraciones superiores a 10 ppm. Se concluye que el tratamiento con el cebo Fipronil en campos de caña de azúcar pueden aumentar significativamente tanto el crecimiento como la producción de caña de azúcar. Más aún, se sugiere que el Fipronil a bajas concentraciones puede tener un efecto fitoestimulador en plántulas de sorgo.
COMBATING SUGARCANE PESTS IN SOUTH AFRICA: FROM RESEARCHING BIOTIC INTERACTIONS TO BIO-INTENSIVE INTEGRATED PEST MANAGEMENT IN THE FIELD

By

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KEYWORDS: Chilo, Eldana, IPM, Induced Resistance, Direct and Indirect Resistance.

Abstract

THE MOST common definition of conventional Integrated Pest Management (IPM) is ‘a decision-making process using multiple pest management tactics to prevent economically damaging out-breaks while reducing risks to human health and the environment’. Low–level IPM is the most often employed form, consisting of the most basic of IPM practices—scouting and insecticide applications according to economic thresholds. Some growers have progressed to medium–level IPM, the adoption of a few additional preventive measures, e.g. cultural controls and plant resistance, coupled with efforts to cut back on broad spectrum pesticide use in order to protect beneficial organisms. These IPM strategies are mainly targeted towards single pest species and do not consider all of the pests in a specific agro-ecosystem. High–level, or Bio-intensive IPM, is where multiple interventions are integrated in a bio-intensive approach targeting multiple pests. Bio-intensive IPM is based on holistic agro-ecosystem interactions, in which knowledge about insects, their symbionts, pathogens, natural enemies, plants, endophytes and interactions between all of these are combined to develop IPM in an area-wide, environmentally friendly manner. Reviewed here are advances in knowledge of, and of biotic interactions between direct, indirect and induced plant resistance, plant nutrition, habitat management, chemical ecology, natural enemies, soil-health, micro-organisms such as endophytic fungi and Wolbachia and phylogenetics and phylogeography. All of these are potential building blocks of a bio-intensive IPM system under-construction at SASRI. Also discussed are opportunities and challenges in these areas of research, taking into account bio-security threats to the South African sugar industry and possible limitations in current sugarcane plant breeding material.

Introduction

SASRI has been working to improve control of the African sugarcane stalk borer Eldana saccharina Walker (Lepidoptera: Pyralidae) since the early 1970s (Carnegie, 1974). A few cultural control measures (Carnegie, 1981; Carnegie and Smaill, 1982) and several less susceptible varieties have been developed against it (Keeping, 2006).

However, it still remains a pest throughout the sugar industry (Webster et al. 2005, 2009).

In order to build resilience into the sugarcane agro-ecosystem, a refocusing of control efforts into a bio-intensive area-wide integrated pest management approach is necessary (Klassen, 2005). Such an approach marries conventional control options with ecologically based new technologies.
such as delineation of within species populations, chemical ecology, stimulo-deterrent diversion (push-pull) and enhancement of natural enemies through habitat management and good soil health practices, to produce sustainable IPM strategies applicable across large areas involving multiple stakeholders (Conlong and Rutherford, 2009).

There is also a need to refocus bio-security to again build resilience to invasion into agro-ecosystems, rather than building walls around them (Waage and Mumford, 2008). One such regional threat is the spotted sugarcane stem-borer, *Chilo sacchariphagus* (Bojer) (Lepidoptera: Crambidae).

This pest originates in South-East Asia and is largely restricted to *Saccharum* as host plants (Bleszynski, 1970). *C. sacchariphagus* is now present in Mozambique and is an imminent bio-security threat to the South African, Malawian, Tanzanian and Swazi sugar industries (Way and Turner, 1999).

**IPM–From the bottom up**

Plant resistance to pests and diseases can be linked to optimal physical, chemical and, biological properties of soil (Altieri and Nicholls 2003; Zehnder et al., 2007). ‘Healthy’ soil is described as having sufficient organic matter to support a high diversity of animal (arthropods, nematodes etc.) and microbial life. Soils can act as important reservoirs for a diversity of entomopathogenic fungi and nematodes, as well as predaceous arthropods, which can contribute significantly to the regulation of pest populations (Keller and Zimmerman, 1989).

Ninety percent of insect pest species spend at least part of their life cycle in soil (Villani and Wright, 1990; Kaya and Gaugler, 1993). In addition, pests that occasionally come into contact with soil can be attacked by predators or become infected by entomopathogens (Klingen et al., 2002). After the harvest of heavily infested sugarcane, the residual *E. saccharina* population from which infestation of the following ratoon crop can be expected is found in the sugarcane stubble at soil level and in the stool below ground.

By minimising compaction and tillage, and by mulching and increasing organic matter, soils can support increased populations of entomopathogenic fungi, entomopathogenic nematodes and predaceous arthropods such that these natural enemies of insects can be included in the suppression of pests in a conservation biological control strategy (Landis et al., 2000; Meyling and Eilenberg, 2007).

**Direct and indirect host-plant resistance**

Insect resistance in grasses is the result of many defence mechanisms that act in parallel to limit the damage of herbivore attacks. Many of these defence mechanisms are based on plant secondary metabolites, or defensive proteins that directly affect the herbivore due to their toxic, deterring or anti-nutritional properties.

Structural resistance also occurs. Keeping and Meyer (2002) have shown that resistance to *E. saccharina* can be enhanced using soil-applied silicon, which becomes incorporated into the plant alongside lignin and fibre increasing resistance to penetration. These authors emphasise a relationship between nitrogen and silicon nutrition whereby the ratio of these elements determined in leaf analyses can be used as an indicator of *E. saccharina* infestation risk. Keeping and Rutherford (2004) have reviewed mechanisms of direct resistance to *E. saccharina*.

Two decades ago, a new type of defence mechanism, termed indirect defence, was first described in maize (Turlings et al., 1990). Central to this type of defence is the release of a volatile plant SOS signal, a mixture of volatile secondary metabolites.

Plant volatiles are derived from complex biochemical processes and include fatty-acid-derived products [methyl-jasmonate, cis-jasmonate, and green leaf volatiles (GLV) like hexenal and hexenyl-acetate], monoterpenes, sesquiterpenes, and shikimic acid-derived products [e.g. methyl-
salicylate and indole] (Turlings et al., 1998; Ferry et al., 2004). These can serve as signals, not only to attract predators and parasites of attacking herbivores, but they can also repel the herbivore itself, and they can elicit responses in neighbouring undamaged plants (Bruin et al., 1995; De Moraes et al., 2001). The use of elicitors to directly activate or prime resistance shows much promise as an IPM tool (Zehnder et al., 2007).

**Habitat management**

Therefore, it is very important to understand the role of plants in managing insect populations. An example comes from our experience in trying to control E. saccharina with indigenous and new association biological control agents.

Conlong et al. (2007) found that female E. saccharina moths will accept Cyperus papyrus and Cyperus dives as host plants in preference to the indigenous grass Pennisetum purpureum, with sugarcane being least preferred.

A preference was again demonstrated by Keeping et al. (2007), who showed that, if given the choice between older sugarcane and maize, E. saccharina would oviposit on the maize, even if it were Bt maize.

Keeping et al. (2007) further showed that larval survival on this Bt maize was zero. A hierarchical oviposition preference (Thompson and Pellmyr, 1991) is suggested in Southern African E. saccharina females, with most oviposition found on or close to its indigenous sedge hosts, followed by indigenous grasses, and then sugarcane.

However, a large proportion of these eggs were not laid directly on the plants, but in cryptic oviposition sites in the vicinity of potential host plants (Kasl, 2004; Barker, 2008).

Thompson and Pellmyr (1991) suggest that egg dumping is behaviour of highly polyphagous species (E. saccharina attacks species of the Cyperaceae, Typhaceae, Juncaceae and Graminaceae (Atkinson, 1980; Conlong, 2001; Mazodze and Conlong, 2003)), or in species associated with superabundant host plants.

These are both possibilities with E. saccharina in sugarcane and its cyperaceous hosts, as both hosts occur in large essentially mono-specific stands. Adult females therefore may not be particularly attracted by host or ‘pull’ plants in an IPM system and conversely they may be more strongly repelled by non-host or ‘push’ plants, since the presence of these could indicate that the insect had reached the edge of the preferred mono-specific host plant stand.

Nevertheless, E. saccharina seems to have a hierarchical preference in choosing a host plant habitat to oviposit in, i.e. Cyperaceae and maize, both of which have E. saccharina population controls in place; natural enemies in the Cyperaceae (Conlong, 1990, 1997, 2000) and genetically engineered Bt toxin in maize (Keeping et al., 2007).

Further evidence to promote habitat management as a control option was provided by Khan et al. (1997a, 2001) who demonstrated the repellent ‘push’ properties of the indigenous grass Melinis minutiflora Beauv. to cereal stemborers, and also its attractant properties to their parasitoids (Khan et al., 1997b). M. minutiflora produces volatiles similar to damaged maize, even in the absence of pest damage to itself (Gohole et al., 2003).

Stimulo-deterrent diversion using M. minutiflora has been successfully deployed against the spotted stemborer, Chilo partellus (Swinhoe) (Lepidoptera: Crambidae), in Central African maize (Cook et al., 2007; Khan et al., 1997a,b).

In a glasshouse experiment at SASRI, Xanthopimpla stemmator (Thunberg) (Hymenoptera: Ichneumonidae) parasitised more E. saccharina pupae in sugarcane in close proximity to this grass, than in sugarcane only (Figure 1) (Kasl, 2004). This suggests that the searching behaviour of the parasitoid was increased by Melinis volatiles.
The next phase in developing this habitat management approach for *E. saccharina* was to set up field trials using rows of *M. minutiflora* along either in irrigation or contour breaks as a repellent or ‘push’ plant. *E. saccharina* populations and damage were halved in field plots planted next to strips of *M. minutiflora* compared to control plots, suggesting that the pest was repelled by *Melinis* volatiles (Figure 2) (Barker *et al*., 2006). Planting *Cyperus papyrus* as a trap, or ‘pull’ plant along drainage lines of selected sugarcane fields resulted in significantly reduced damage in the cane associated with it (Figure 3) (Kasl, 2004).

Fig. 1—Total *Eldana saccharina* pupae parasitised by *Xanthopimpla stemmator* when offered on companion plants (unshaded bars) and on sugarcane (shaded bars). Total number of parasitised pupae, from 100 pupae offered per experiment, indicated by circular points. Plants were tested in two groups. (K–Kenyan; S–South African; A–Australian) (from Kasl, 2004).

Fig. 2—Mean percent internodes damaged and *E. saccharina* numbers in cane planted with (at 20 row intervals) and without *Melinis minutiflora* (differences significant at *p* < 0.001 within each measure) (from Barker *et al*., 2006).
Fig. 3—Monthly damage levels in sugarcane (var. NCo376) adjacent to Cyperus papyrus stands (shaded bars), and in control sugarcane not associated with C. papyrus (unshaded bars). * Means (+1 SD) significantly higher in paired tests at $\mu = 0.05$ (from Kasl, 2004).

Based on the success of these trials, a farm based habitat management plan has been devised, incorporating indigenous host plants and Bt maize as ‘pull’ plants for *E. saccharina* and *M. minutiflora* as the ‘push’ component. This bio-intensive approach has been expanded into a Bio-intensive-IPM plan, incorporating plant nutrition, soil health and the use of less susceptible sugarcane varieties (Figures 4 and 5).

An added aspect to the plan is to plant buckwheat at the time of sugarcane planting. This is to attract adult parasitoids and predators into the sugarcane environment by providing a pollen and nectar source for their survival during periods of low host availability, much the same as advocated
by Wäckers et al. (2005) and Zehnder et al. (2007) in their conservation biological control approach to enhance the activity of indigenous natural enemies.

**Does sugarcane emit SOS volatiles when attacked by *E. saccharina***?

In contrast to the situation in the natural hosts of *E. saccharina*, negligible parasitism has been recorded in sugarcane, even when this crop was planted adjacent to infested indigenous host plants with abundant parasitoids present (Conlong and Hastings, 1984). Many introduced parasitoids have also failed to colonise the sugarcane habitat (Conlong, 1997).

Using gas chromatography, Smith et al. (2006) showed different volatile emission patterns between *Cyperus papyrus* infested by *E. saccharina* and uninfested *C. papyrus*. Infested sugarcane was neither qualitatively or quantitatively different from uninfested sugarcane and both were different from *C. papyrus* (Figure 6). In addition, these authors showed that the parasitoid *Goniozus indicus* (Ashmead) (Hymenoptera: Bethylidae) was attracted to frass from *E. saccharina* that had...
fed on *C. papyrus*, and was not attracted to frass from *E. saccharina* that had fed on sugarcane. Adding this to the lack of parasitism recorded in sugarcane, even in the vicinity of natural host plants harbouring parasitoids, suggests that modern sugarcane genotypes may not attract natural enemies through the release of herbivore induced SOS volatiles, or that they may differ in the ability to do so.

![Fig. 6—Gas chromatograms of volatiles released by (a) uninfested *C. papyrus*, (b) infested *C. papyrus*, (c) uninfested sugarcane variety N11 and (d) infested sugarcane variety N11 (Ψ= compounds showing major differences–volatiles were not identified) (from Smith et al., 2006).](image)

**Genotypic differences in plant volatile emission**

The ability to mount indirect defence against *E. saccharina* may have been lost in sugarcane as a result of inadvertently concentrating on direct resistance in a monoculture oriented plant breeding selection program. Besides this possibility, the release of plant volatiles is characterised by a large degree of genotypic variation within plant species, for example, maize genotypes and their closest wild relatives, *Zea mays* ssp. *parviglumis* and *mexicana* (collectively known as teosinte), show significant differences in emissions when attacked (Gouinguene et al., 2001; Degen et al., 2004).

An example of loss of indirect defence has been found below ground in maize. In response to feeding by the western corn rootworm, *Diabrotica virgifera virgifera* (LeConte) (Coleoptera: Chrysomelidae), maize roots release (E)-b-caryophyllene that attracts the entomopathogenic nematode *Heterorhabditis megidis* (Rasmann et al., 2005). Most North American maize lines do not release (E)-b-caryophyllene in response to rootworm attack, whereas many European lines and teosinte accessions do (Kollner et al., 2008).

The existence of genotypic differences in the emission pattern of volatile compounds for Kenyan *M. minutiflora* cultivars has also been demonstrated (Gohole et al., 2003). The lack of response by *X. stemmator* in the presence of Australian *M. minutiflora* again points to variability within this species (Figure 1). Australian *M. minutiflora* is extensively used for cattle fodder. The strong odour of the plant can be carried through to milk and, because of this, there has been an
extensive program to breed a less volatile variety with similar nutritional quality. The volatile(s) that the parasitoid responded to in the African variety could have been bred out of the Australian variety, as explained by Pickett and Woodcock (1993).

**Breeding for artificially primed and induced resistance**

The loss of the ability to produce an SOS volatile and the observed genotypic variability in their production by maize points towards the exploitation of the phenomenon in sugarcane, by breeding varieties for enhanced attractiveness to natural enemies (Bottrell et al., 1998). This could be achieved through the application of an artificial elicitor followed by selection for enhanced direct and indirect resistance in a system that includes natural enemies.

Experimental application of elicitors is fairly simple and it is worth trying to make selections among plant breeding lines grown under the influence of plant defence elicitors, aiming for new cultivars optimised for artificially inducible resistance traits without significant yield penalty (Agrawal et al., 2002; Ahman, 2006). Historically, induced resistance research has mostly concentrated on direct activation where resistance is expressed in advance of challenge by the pest. The possibility of priming as a mechanism of protection has often been overlooked because it only becomes apparent in challenged plants. Priming equates to a ‘heightened state of readiness’, in that in the event of damage to a primed plant, resistance responses are faster and more intense (Conrath et al., 2006).

Direct activation of resistance might best be employed where the target pest is widespread and has predictable outbreaks. An example is the sugarcane thrips, Fulmekiola serrata (Kobus) (Thysanoptera: Thripidae) that affects more than two thirds of sugarcane plants in a particular field at the same time. Outbreaks occur in summer with numbers peaking every January since the pest was first discovered on the African continent in 2004 (Way et al., 2006). Primed resistance would, however, be more suitable for E. saccharina, since a much lower proportion of plants is attacked and infestations tend to be patchy.

**Ecology and phylogeography**

The basic building block of IPM is still regarded as ecology (Gurr et al., 2003). In a study of E. saccharina, Conlong (2001) found behavioural, host plant and natural enemy differences in populations occurring between South, Central and West Africa, with them seemingly coming together in Uganda.

These confusing factors between different populations of what is otherwise a morphologically similar species made it an ideal candidate for molecular systematic analyses. Assefa et al. (2006), using the cytochrome oxidase subunit 1 (CO1) region of the mitochondrial genome, separated E. saccharina into three distinct groups (west, south and Ethiopian). Two of these groups (west and south) were found in Uganda.

The CO1 genetic diversity between these groups was larger than that between recognised species within the genus Ostrinia (Lepidoptera: Crambidae) (Coates et al., 2005). In other insects, unexpected mtDNA CO1 patterns have led to the discovery of cryptic species (Hebert et al., 2004; Smith et al., 2007). Such diversity should encourage us to confirm covarying genetic, behavioural and ecological characteristics which would lend support to the notion that cryptic species exist within the E. saccharina complex.

In IPM programs which use classical biocontrol as one of their management options, or translocation of natural enemies (Schulthess et al., 1997), these aspects can be enhanced by using such techniques to identify cryptic species, or populations of species most closely related to each other, so that more informed decisions can be made regarding natural enemy selection for use against pests. This applies not only to pest species, but also to parasitoids (Dittrich et al., 2006; Muirhead et al., 2006; Ngi-Song et al., 1998).
Since 1992, surveys for indigenous parasitoids of *E. saccharina* in a variety of African habitats have been completed. Thirty species of larval parasitoids have been found in eight countries (Conlong, 2000). Several of these have failed to parasite *E. saccharina* from South Africa due to incompatibility. For example, from West Africa, *Descampsina sesamiae* (Diptera: Tachinidae) larvae are encapsulated by *E. saccharina* (Conlong, 1997). *Cotesia sesamiae* (Cameron) (Hymenoptera: Braconidae) from South Africa is also unsuccessful as eggs are encapsulated (Potting *et al*., 1999). Further collections of parasitoids from Central Africa, where southern and western populations of *E. saccharina* co-exist, could reveal biotypes of parasitoids that could be effective against this pest (Muirhead *et al*., 2006; Ngi-Song *et al*., 1998).

**Wolbachia**

These obligate intracellular bacteria (Phylum α-Proteobacteria: Family Rickettsaceae) are commonly found in diverse insect taxa and can profoundly alter their host’s reproduction. They are maternally inherited, residing mostly in the reproductive tissues of their hosts and it has been suggested that they may infect over 70% of arthropod species worldwide (Jeyaprakash and Hoy, 2000).

In their reviews on the biology of *Wolbachia*, Werren (1997), Floate *et al.* (2007) and Bourtzis (2007) all regard the symptoms of infection such as feminisation of genetic males, male embryo killing and cytoplasmic incompatibility (CI) as potentially useful characters for insect population regulation. Attempts have been made to exploit CI as a method to suppress natural populations of pests in a way analogous to the sterile insect technique through the release of incompatible infected male insects (Brower, 1980). Alternatively *Wolbachia* could be introduced into South African *E. saccharina* (populations of which are currently free of infection) using hybrid introgression and field release.* Wolbachia* have potential as a new type of biological control agent by altering the reproductive success of their hosts and probably also that of parasitoids (Fytrou *et al*., 2006).

Recent results (Rutherford, unpublished) have confirmed the presence of *Wolbachia* in *E. saccharina* from Kenya, Uganda and Tanzania, all close to the probable centre of origin for *E. saccharina*, while it is absent from *E. saccharina* populations in western and southern Africa. This now opens up the potential use of *Wolbachia* in our IPM strategy.

**The interaction between *E. saccharina* and *Fusarium***

When *E. saccharina* bores in sugarcane, the tissue surrounding the boring becomes reddish discoloured often affecting a whole internode. Following on from this, and work of Schulthess *et al.* (2002), McFarlane *et al.* (2009) cultured numerous *Fusarium* spp. isolates, from the red tissue surrounding *E. saccharina* borings, as well as from undamaged stalks as endophytes. Most of the isolates from borings were beneficial to *E. saccharina* in artificial diet in terms of larval survival and growth rate, and were attractive to neonates in olfactory choice assays. A few of the endophytic isolates were antagonistic, with *E. saccharina* neonates repelled and growth retarded. Moths may also be attracted or repelled depending upon isolate. Ako *et al.* (2003) showed that West African *E. saccharina* females laid on average 32 eggs on maize stalks with *F. verticillioides* present as an endophyte, versus nine on stalks grown from fungicide or hot water treated seeds.

In an integrated control approach against *E. saccharina*, seedcane hot water treatment and/or treatment with fungicides could reduce endophytic colonisation by *Fusarium* isolates beneficial to *E. saccharina*, thereby reducing the chance of infestation. Alternatively, the facilitation of endophytic colonisation of sugarcane by *Fusarium* isolates antagonistic to *E. saccharina* could afford more sustainable and environmentally friendly protection from this stalk borer. Another approach could be to exploit the differences in volatiles between repellent and attractive isolates in the development of repellents and lures of use in the field.
Concluding remarks

Khan et al. (1997a) described a ‘push–pull’ system effective against cereal stem borers in maize. This system includes the indigenous parasitoid Cotesia sesamiae as well as C. flavipes which was introduced against the exotic Chilo partellus (Overholt et al., 1997). C. sacchariphagus, now present in Mozambique, is being parasitised by both C. flavipes and X. stemmator on larvae and pupae respectively in sugarcane (Conlong, pers.comm). Ngumbi et al. (2005) showed that C. flavipes females respond to terpenoids and the green leaf volatiles which are released by maize plants damaged by C. partellus. This suggests that sugarcane may produce SOS volatiles in response to C. sacchariphagus.

There are alternative hypotheses to that of loss of ability to produce SOS volatiles. By boring the tops of stalks and leaf spindles in young cane, volatile emission could be elicited by C. sacchariphagus, whereas E. saccharina may avoid eliciting volatile emission by boring the bottoms of stalks in older cane. Another hypothesis is that the Fusarium associated with E. saccharina could interfere with the elicitation of volatile emission or change the composition of emitted volatiles. These possibilities are worthy of further investigation.

Nevertheless, a bio-intensive IPM strategy could be made more effective if the crop itself is capable of releasing appropriate SOS volatiles when attacked. Breeding varieties for enhanced attractiveness to natural enemies has potential if natural enemies are already present in the habitat management system. Goniozus indicus parasitises E. saccharina in C. papyrus. It is also known to parasitise C. partellus (Keiji and Overholt, 1996) and has been found doing so in Sorghum arundinaceum growing in proximity to C. papyrus (Conlong, 1994; 1997). It is therefore possible that G. indicus could parasitise both C. sacchariphagus and E. saccharina in sugarcane. The same applies to the pupal parasite X. stemmator.

Conlong et al. (2004) showed that some of the varieties with the highest direct resistance to E. saccharina were the most susceptible to C. sacchariphagus and vice-versa. This has implications for variety choice in an IPM system designed to target both pests simultaneously, should C. sacchariphagus invade the South African sugar industry. Given increasing adoption of the ‘push-pull’ habitat management concept even in the absence of parasitoid activity against E. saccharina in sugarcane, and its success against C. partellus in maize, we are confident that ‘push-pull’ habitat management will also be effective against C. sacchariphagus.

The development of IPM strategies depends on a sound understanding of the chemical ecology of pest interactions with sugarcane, natural enemies and the habitat. Modern IPM is not only about insect/plant interactions, it is about holistic agro-ecosystem interactions, in which increased knowledge about the environment, soils, plants, pathogens, endophytes, symbionts and insects are all combined to provide effective crop protection in an environmentally friendly manner.

As knowledge about, and interactions between, induced plant resistance, chemical ecology, micro-organisms such as endophytic fungi and Wolbachia, and phylogenetics and phylogeography of arthropods becomes more easily available, it is hypothesised that these will become important components of bio-intensive AW-IPM, thereby minimising the impacts of synthetic pesticides even more (Conlong and Rutherford, 2009).

REFERENCES


LA LUTTE CONTRE LES RAVAGEURS DE LA CANNE À SUCRE EN AFRIQUE DU SUD: DE LA RECHERCHE DES INTÉRACTIONS BIOTIQUES À LA LUTTE INTÉGRÉE BIO-INTENSIVE

Par

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MOTS CLÉS: Chilo, Eldana, Lutte Intégrée, Induction de la Résistance, Résistance Directe et Indirecte.

Résumé

LA DEFINITION la plus courante de la lutte intégrée contre les ravageurs (IPM) est « le processus décisionnel de gestion des ravageurs sur la base de stratégies multiples afin de prévenir les attaques avec des conséquences économiques, tout en réduisant les risques à la santé humaine et à l’environnement ». L’IPM de faible niveau est la forme la plus couramment utilisée, comprenant les pratiques de base de l’IPM – prospections et applications des insecticides en conformité avec les seuils économiques. Certains planteurs ont progressé jusqu’au niveau intermédiaire de L’IPM en adoptant quelques pratiques préventives additionnelles, comme les pratiques culturales et les variétés résistantes, en plus des efforts visant à diminuer les applications de pesticides à large spectre dans le but de protéger les organismes bénéfiques. Ces stratégies de l’IPM se focalisent principalement à une espèce de ravageur et ne considèrent pas l’ensemble des ravageurs d’un agro-écosystème spécifique. Par contre, l’IPM de haut niveau ou bio-intensif comprend des interventions multiples qui sont intégrées dans une approche ciblant plusieurs ravageurs. L’IPM bio-intensif est basé sur les interactions holistique de l’agro-écosystème, dans lequel la connaissance des insectes, leurs symbiontes, les pathogènes, les ennemis naturels, les plantes, les endophytes ainsi que leurs interactions, sont combinés pour développer un IPM adéquat tout en étant respectueux de l’environnement. Les avancées de nos connaissances sur les interactions biotiques directes et indirectes, l’induction de la résistance, la nutrition de la plante, la gestion de l’habitat, l’écologie chimique, les ennemis naturels, la qualité biologique du sol, les microorganismes comme les champignons endophytes, la bactérie Wolbachia, la phylogénétique et la phylogéographie sont passés en revue ici. Tous ces thèmes sont des composantes potentielles d’un système IPM bio-intensif en développement au SASRI. Les opportunités et défis dans ces thématiques de recherche sont aussi élaborées, en tenant compte des menaces de biosécurité à l’industrie sucrière d’Afrique du Sud et les limitations possibles du matériel génétique pour l’amélioration de la canne à sucre.
EL COMBATE DE LAS PLAGAS DE LA CAÑA DE AZÚCAR EN SUDAFRICA:
INVESTIGACIÓN DESDE LAS INTERACCIONES DE BIOTICOS HASTA
EL MANEJO INTEGRAL BIO-INTENSIVO EN EL CAMPO

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PALABRAS CLAVE: Chilo, Eldana, MIP, Resistencia Inducida,
Resistencia Directa e Indirecta.

Resumen
LA DEFINICIÓN convencional más común de Manejo Integral de Plagas (MIP) es ‘un proceso de
toma de decisiones usando tácticas de manejo múltiples para prevenir brotes de insectos que causen
daño económico mientras se reducen los riesgos a la salud humana y al ambiente’. El MIP de bajo
nivel es la forma más común empleada, y consiste en el uso de las practicas básicas de monitoreo y
aplicaciones de insecticidas de acuerdo con umbrales económicos. Algunos cultivadores han
progresado a un nivel medio de MIP, la adopción de unas pocas medidas preventivas adicionales,
p. e., control cultural y resistencia de plantas, acopladas con esfuerzos de reducir el uso de
plaguicidas de amplio espectro con el fin de proteger organismos benéficos. Estas estrategias de
MIP son principalmente dirigidas hacia una sola especie de insecto y sin considerar todas las plagas
de un agro ecosistema en particular. Alto – nivel o MIP Bio – intensivo, en donde muchas
intervenciones se integran en un enfoque Bio- intensivo enfocándose a muchas plagas. MIP Bio –
intensivo se basa en interacciones holísticas del agro ecosistema, en las cuales el conocimiento de
los insectos, sus simbiontes, patógenos, enemigos naturales, plantas, endofíticos e interacciones
entre todos estos enfoques se combinan para desarrollar el MIP en un área amplia, de una manera
amigable con el ambiente. Por tanto, aquí se revisan los avances en el conocimiento de y de las
interacciones bióticas entre directas, indirectas y resistencia inducida en plantas, nutrición de las
plantas, manejo del hábitat, ecología química, enemigos naturales, sanidad del suelo,
microorganismos tales como hongos endofíticos, Wolbachia, la filogenia y filogeografía. Todos
estos son componentes potenciales para construir un sistema de MIP Bio – intensivo en SASRI.
También se discuten las oportunidades y desafíos en estas áreas de investigación, tomando en
consideración amenazas de bio seguridad a la industria azucarera de Sur África y las posibles
limitaciones a los actuales materiales de mejoramiento de plantas de caña de azúcar.
IMPACT OF GLOBALISATION ON SUGARCANE PESTS,
BIODIVERSITY AND THE ENVIRONMENT:
A REVIEW OF THE 2009 ENTOMOLOGY WORKSHOP

By

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KEYWORDS: Biological Control, Pest Management,
Insect-Plant Interactions, Yield Losses, Biological Studies.

Abstract

The 7th International Society of Sugar Cane Technologists (ISSCT) Entomology Workshop was held from 20 to 24 April 2009 in San Miguel de Tucumán, Argentina under the theme: ‘Impact of Globalisation on Sugar Cane Pests, Biodiversity and the Environment’. Technical sessions held over three days were grouped into five subject headings: biological control of sugarcane pests; pest management; insect-plant interactions; losses due to sugarcane pests; and biological studies of sugarcane pests. Following the technical sessions, field trips allowed delegates to view important insect pests of the Argentine sugarcane industry in the field and visit the Estación Experimental Agroindustrial Obispo Colombres, as well as cultural sites in the region surrounding San Miguel de Tucumán. The Entomology section concluded that globalisation will most likely continue to impact on the world’s sugarcane industries. The ISSCT Entomology Workshops will therefore become increasingly important as a venue for entomologists to stay abreast of impending insect threats to their industries and to keep current with new technologies that will be vital for managing potential new invaders as well as maintaining sustainability.

Introduction

The 7th ISSCT Entomology Workshop was held from 20 to 24 April 2009 in San Miguel de Tucumán, Argentina. The Estación Experimental Agroindustrial Obispo Colombres hosted the workshop that enabled entomologists from 11 countries to share research findings under the theme: ‘Impact of Globalisation on Sugar Cane Pests, Biodiversity and the Environment’. Seventeen technical presentations were made during the first three days of the workshop. The presentations covered the topics of biological control of sugarcane pests, pest management, insect-plant interactions, losses due to sugarcane pests, and biological studies of sugarcane pests. As always, an active discussion period was held at the end of each session.

A series of field trips was provided to complement the technical sessions. One day was set aside to visit selected field sites. One stop highlighted the clean seed program that provided micro-propagated seed to participating growers. At other sites, delegates were able to view damage caused by the stem borer Elasmopalpus lignosellus and, at another, the stem borer Diatraea saccharalis.
The final stop was at a commercial field where delegates were able to view damage by the weevil *Acrotomopus actropunctellus*. Lunch was provided by a local mill. The mill manager spoke to the group about processing and also enlightened the group about a consortium of mills planning to venture into the area of ethanol production. The following day the delegates were given a tour of Estación Experimental Agroindustrial Obispo Colombres. This experiment station is one of the oldest in the world and coincidently is celebrating its centenary year in 2009. During the field tours, the delegates visited the region around San Miguel de Tucumán that included a visit to an archaeological site once inhabited by the indigenous people of this region of Argentina.

**Opening**

Dr Daniel L. Ploper, Head of the Estación Experimental Agroindustrial Obispo Colombres, opened the meeting by stressing the importance of the ISSCT workshops as venues for scientific exchange and the establishment of scientific contacts. Eng. Carlos Mirande, ISSCT Councillor from Argentina [Sociedad Argentina de Tecnico de la Caña de Azucar (S.A.T.C.A.)] and Mr Juan José Budeguer, president of the Board of Estación Experimental Agroindustrial Obispo Colombres also welcomed the attendees to the workshop and expressed their desire for a successful meeting. Dr Silverio Flores Cáceres, Honorary President of the 2010 ISSCT Congress, also welcomed delegates and encouraged all to come to Veracruz, Mexico in 2010. Dr William White, Entomology Section Committee Chairman, presented a historical review of the Entomology Workshops beginning with the first workshop held in 1991. He encouraged everyone to actively participate in the discussions as all could contribute to the workshop and their participation was important to group synergy.

**Biological control of sugarcane pests**

Biological control continues to be an important component of pest management by the world’s sugarcane industries. Even an industry like Louisiana that relies heavily on insecticides to control its key insect, *Diatraea saccharalis*, has found that the use of green chemistry can have a profound positive impact on beneficial insects inhabiting sugarcane fields. Researchers in Louisiana found that, following the labelling and wide-spread use of the insect growth regulator (IGR) tebufenozide, the carabid beetle *Leptotrachelus dorsalis* is now able to successfully exploit sugarcane fields once denied it by broad spectrum contact insecticides. This beneficial insect appears to be a good candidate for future research in biological control in Louisiana.

While the impact of biological control in the field is often reported, the socio-economic impact of biological control is often under-publicised. In one documented case in Thailand, total benefits of US$224-473 per hectare were realised with cost:benefit ratios of 0.12 and 0.33. The additional benefits to the environment and human health have not yet been taken into account.

*Cotesia flavipes* remains an important biological control agent of stem borers around the world. However, advances in mass rearing are needed to reduce the time and financial investment required to produce this parasitoid. Researchers in Argentina have found that production of cocoons was 8% higher following one inoculation rather than two. They also found that stinging 18 and 19 day-old larvae produce the most adults and female moths, while the ratio of males:females decreased from larvae 17 days old to 21 days.

Thailand has five important species of lepidopterous stem borers: *Chilo tumidicostalis, C. infuscatusellus, C. sacchariphagus, Sesamia inferens,* and *Scripophaga excerptalis*, as well as a longhorn beetle stem borer, *Dorysthenes buqueti*. Fortunately, a number of beneficial insects are present for biological control. These beneficial insects plus the stage of growth and nutritional condition of the cane plants play an important role in determining the level of damage incurred by Thai cane growers.

French researchers from INRA, FDGDON and CIRAD have developed an effective program for controlling the stem borer *C. sacchariphagus* on Réunion Island with the egg parasitoid, *Trichogramma chilonis*. However, they too are searching for ways to improve efficiency
of mass propagation of the parasitoid so that overall costs associated with the program can be lowered. Their approach is to develop cold-storage technology. Initial results have already defined biotic and abiotic parameters required for successful storage for up to two months.

**Pest management**

The main sugarcane pests in Mauritius are the stem borer *Chilo sacchariphagus*, the armoured scale *Aulacaspis tegalensis*, the soft scale *Pulvinaria iceryi*, the white grub *Heteronychus lica*, and armyworms *Mythimna* spp. Mauritius has a long history of successful biological control of these pests. However, with increased mechanisation of field operations to reduce production costs, major changes are occurring in the sugarcane landscape, causing a shift from a diverse habitat to one where sugarcane monoculture predominates. Researchers are investigating ways of creating conservation areas and undisturbed areas that would enhance the natural enemy populations and thus control incipient outbreaks of the pests.

The sugarcane leafhopper *Perkinsiella saccharicida* continues to be an important pest in Ecuador. While researchers continue to look for new and more effective biological control agents, an integrated pest management (IPM) approach that includes use of insecticides appears to be the approach most likely to succeed. However, insecticide application must be done in such a way as to minimise the risks to natural enemies.

Entomologists in South Africa are also focusing on an IPM approach with combinations of varietal resistance, cultural (planting date manipulation) and insecticide options to manage sugarcane thrips, *Fulmekiola serrata*. Research continues to be conducted to determine just how much yield loss is associated with thrips feeding.

White grubs continue to be the most important pests of sugarcane in Australia. Many growers in Australia are adopting new farming practices, i.e. legume rotations, controlled traffic and minimum tillage for economic and agronomic reasons and this may have positive or negative effects on white grub populations and damage. Existing insecticide recommendations may also be affected. Results of field trials are being included in guidelines for growers to manage white grubs in these systems.

**Insect-plant interactions**

Sugarcane is attacked by a complex of insect pests including stalk borers and leaf-sucking insects. In the U.S., two of these insect pests, the Mexican stem borer *Eoreuma loftini* and the sugarcane aphid *Melanaphis sacchari*, conform in their herbivore-plant interactions to the plant stress hypothesis.

The plant stress hypothesis predicts that environmental stresses on plants decrease plant resistance to insect herbivory by altering biochemical source–sink relationships and foliar chemistry, leading to more palatable food.

High-performance liquid chromatography analysis of whole leaf tissues indicates that several essential free amino acids increased in sugarcane leaves under drought stress. This increase was also associated with enhanced Mexican rice borer oviposition and injury.

Analysis of phloem sap composition of susceptible and resistant varieties revealed that two essential free amino acids (histidine and arginine) were missing in the phloem sap of an aphid-resistant variety. This change in amino acid content may also be associated with plant stress.

While *E. loftini* is a pest of stressed sugarcane, the stem borer *Diatraea saccharalis* is a pest of vigorously growing cane. Work in Argentina was conducted to investigate if fertilisation rates were associated with *Diatraea saccharalis* infestations.

When plots were fertilised with half of the standard rate, no differences were found between treated and control plots with respect to infestation levels. The researchers concluded that the gains in yield from proper fertilisation are greater than any increase in damage by the sugarcane borer.
Losses due to sugarcane pests

Assessing the losses due to insect feeding is a critical component in pest research. Dispersion of scarce research funds, as well as establishing action thresholds and other IPM management decisions, all depend on evaluations of pest losses. The sugarcane borer, *Diatraea saccharalis*, is the most important insect pest in Tucumán. Researchers there evaluated three varieties and determined field and factory losses due to this stem borer. Losses of 0.42% in stalk weight and 0.20% in pol of sugarcane were observed for each 1% increase in bored internodes.

In general, foliar feeding by insects is not considered to cause economic losses. However, in Argentina, the grassworm looper, *Mocis latipes*, appears to be an exception to this rule, with results from two separate studies being reported at the workshop. One study measured reductions in stalk weight of 11.3 to 41.2%, height of 1.7 to 20.7%, sugar content of 0.8 to 4.2%, and sugar yields of 13.9 to 42.9% while, in the second study, the average reduction in sugar yield was 58.3%. These studies indicate that the grassworm looper is capable of producing significant losses in sugar production. The differences in yield losses can be explained by cane variety and age of cane at attack.

Biological studies of sugarcane pests

Ecology processes take place within a spatial context, and the distribution of habitat may strongly impact the distribution, dynamics and evolution of natural populations. Today, the effective management of major insect pests requires an understanding of ecological processes involved in agroecosystem-insect pest interactions including the surrounding landscapes. With the growing use of remote sensing and electronic- and computer-based technologies in pest management, there is a real opportunity to understand the temporal and spatial movements of the insect populations as never-before possible. In Australia, a joint project is underway between CIRAD and BSES using new tools such as radiotelemetry, GIS and simulation models to unravel the spatial ecology of the white grub *Dermolepida albohirtum*.

Three species of leafhoppers, *Tomaspis nonozulia, T. australis* and *Tapajosa rubromarginata*, infest sugarcane fields in the Province of Jujuy, Argentina. These insects appear to have become important as pests with the adoption of green harvest and drip irrigation systems. Research has shown that the environmental factor that has the greatest adverse effect on population development is low precipitation during December.

When new pests are discovered attacking the sugarcane crop, rapid identification of the species and elucidation of basic pest biology are important early considerations. In 2003, while monitoring infestations of *Diatraea saccharalis* in Tucumán, a coleopteran larva was found in stalks causing damage similar to that produced by the *D. saccharalis*. Specimens were sent to the Museo de Ciencias Naturales in La Plata, Buenos Aires for identification. Dr Analía Lanteri identified the beetle as *Acrotomopus actropuntellus* (Coleoptera: Curculionidae). This weevil was previously cited by Jaynes in 1929 as occurring in sugarcane fields in Tucumán and Jujuy. The larvae feed on basal internodes, building wide and tortuous galleries, and also weaken the rootstocks where they hibernate. The insects colonise new fields mainly by the movement of seed-cane. Research continues on this emerging pest as its damage is frequently confused with that of the sugarcane borer and has likely been underestimated.

Conclusions

Globalisation is the integration of economic, political, and cultural systems around the world. It can be a force for economic growth but can also have an adverse impact on local agriculture by facilitating the introduction of insect pests and reducing biodiversity, thus increasing the frequency of pest outbreaks. Sugarcane industries will require their entomologists to react to the negative effects of globalisation by maintaining sustainability of their home industries. The ISSCT Entomology Workshops continue to be ideal forums to obtain knowledge on the most recent control
strategies, emerging pest developments and threats, and new technologies useful in unravelling difficult pest, host, and environmental inter-relationships. The 7th ISSCT Entomology Workshop was successful in meeting its obligations to those delegates investing the time and money to attend. Maintaining a high level of knowledge transfer remains an important challenge for organisers of future workshops as travel budgets diminish. Organisers must work hard to attract entomologists from developing and emerging countries, as well as provide services to sugarcane entomologists beyond the workshops, e.g. updating pest compendiums and forming consortiums to provide services unattainable to research institutions working alone.

Acknowledgments

The 7th ISSCT Entomology Workshop was hosted by the Estación Experimental Agroindustrial Obispo Colombres and its representatives Dr L. Daniel Ploper (Director Technico) and Mr Juan José Budeguer (President of the Board of Directors). The workshop was conducted under the auspices of the International Society of Sugar Cane Technologists and the Sociedad Argentina de Tecnicos de la Caña de Azucar (S.A.T.C.A.). The members of the local organising committee were L. Daniel Ploper, Eduardo Willink, Jorge Scandaliaris and Analía Salvatore, with Maria Teresa Vera serving as local coordinator. Support was also provided by Syngenta SA, Instituto de Desarrollo Productivo (IDEP), and Universidad San Pablo Tucumán. These individuals and entities are gratefully acknowledged by the participants, for without them the workshop would not have occurred nor have been so successful.

L’IMPACT DE LA GLOBALISATION SUR LES RAVAGEURS DE LA CANNE À SUCRE, LA BIODIVERSITÉ ET L’ENVIRONNEMENT : UNE REVUE DE L’ATELIER D’ENTOMOLOGIE EN 2009

Par

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MOTS-CLÉS: Lutte biologique, Gestion des Ravageurs, Interactions Insecte-Plante, Effets sur le Rendement, Études Biologiques.

Résumé

Le 7ème Atelier de Travail d’Entomologie de l’International Society of Sugar Cane Technologists (ISSCT) a eu lieu du 20 au 24 avril 2009 à San Miguel de Tucumán, en Argentine, ayant pour thème: «L’impact de la Globalisation sur les Ravageurs de la Canne à Sucre, la Biodiversité et l’Environnement». Les sessions techniques se sont déroulées pendant trois jours et étaient regroupées sous les thèmes suivants: la lutte biologique contre les ravageurs de la canne à sucre; la gestion des ravageurs; les interactions insecte-plante; les pertes occasionnées par les ravageurs; et les études biologiques des ravageurs de la canne. Après les sessions techniques, des visites aux champs ont permis aux délégués d’observer les ravageurs principaux de l’industrie sucrière d’Argentine et de visiter l’Estación Experimental Agroindustrial Obispo Colombres, aussi bien que
les sites culturels de la région de San Miguel de Tucumán. La Section d’Entomologie de l’ISSCT est arrivée à la conclusion que très probablement, la globalisation continuera à affecter l’industrie cannière dans le monde. Les ateliers d’Entomologie seront donc encore plus pertinents comme lieu de rencontre pour que les entomologistes puissent prendre connaissance des derniers développements, en particulier les menaces immédiates des ravageurs sur leurs industries. De plus, ils leur permettront de se familiariser avec de nouvelles technologies, essentielles pour gérer les envahisseurs potentiels et maintenir une lutte durable contre les ravageurs.

IMPACTO DE LA GLOBALIZACION SOBRE LAS PLAGAS DE LA CAÑA DE AZUCAR, BIODIVERSIDAD Y EL MEDIO AMBIENTE: UNA REVISION DEL TALLER DE ENTOMOLOGIA DE 2009

Por

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PALABRAS CLAVE: Control Biológico, Manejo de Plagas, Interacciones Insectos Plantas, Pérdidas de Rendimiento, Estudios Biológicos.

Resumen

El 7th Taller Internacional de Entomología de la Sociedad de Técnicos de la Caña de Azúcar se llevó a cabo entre el 20 y 24 de abril de 2009 en San Miguel de Tucumán, Argentina bajo el lema: “Impacto de la globalización sobre las plagas de la caña de azúcar, biodiversidad y ambiente”. Se desarrollaron sesiones técnicas durante tres días agrupadas en cinco temáticas tituladas: control biológico de las plagas de la caña de azúcar, manejo de plagas, interacciones de insectos y plantas, pérdidas debidas a plagas de la caña de azúcar, y estudios biológicos de plagas de la caña de azúcar. A continuación de las sesiones técnicas, se programaron viajes de campo para permitir a los delegados ver insectos plagas importantes de la industria de la caña de azúcar de Argentina y visitar la Estación Experimental Agroindustrial Obispo Colombres, así como sitios culturales en la región cercana a San Miguel de Tucumán. La sección de Entomología concluyó que la globalización muy probablemente continuará impactando las industrias en el mundo de la caña de azúcar. El taller de ISSCT en Entomología seguirá incrementando su importancia como una herramienta para que los entomólogos se mantengan alertas e impidan las amenazas de los insectos a sus industrias y para mantenerse actualizado sobre nuevas tecnologías que serán vitales para manejar nuevos invasores potenciales así como para mantener la sostenibilidad.
SUGAR LOSSES CAUSED BY THE SUGARCANE BORER
(DIATRAEA SACCHARALIS) IN TUCUMÁN, ARGENTINA

By

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KEYWORDS: Sugarcane, Diatraea saccharalis, Losses.

Abstract

The sugarcane borer, Diatraea saccharalis is the most damaging pest of the sugarcane in Tucumán Province. Galleries produced in the stalk by the larvae are gateways to pathogens. Their effect generates losses in stalk weight, and reduces the quality and amount of sucrose and juice extraction in factories. The objective of this study was to evaluate the losses caused by Diatraea saccharalis on three sugarcane varieties and on cane under storage. During the 2005 harvest seasons, observations with three commercial varieties, LCP 85-384, TUCCP 77-42, and CP 65-357, detected significant losses on field and factory yield. Reductions of 0.42% in the stalk weight and 0.20% in pol were observed for each 1% attack, producing a 0.22% loss for each point of infestation loss on the factory yield, with a 620 to 650 g/t of cane loss of sugar, depending on the variety. In addition, the variety LCP 85-384 was assayed at three different dates: June, August and October, during the 2006 harvesting season, to evaluate the effect of storage on losses following D. saccharalis attack. Sugar losses were much greater after 4 days post harvest storage. This difference was higher as the harvest season progressed.

Introduction

The sugarcane borer, Diatraea saccharalis (F.), is the most damaging sugarcane pest in Tucumán province. Adult moths oviposit on sugarcane leaves. Eggs may be laid singly or in masses, and early instar larvae feed cryptically on leaves, whorls, or other succulent plant tissue. Young shoots die, since D. saccharalis bores into primary shoots killing the apical meristem, which reduces the number of millable stalks per unit area (McGuire et al., 1965). Older larvae, generally third instar and older, feed almost exclusively within tunnels in stalks; there, they are protected, making it difficult to control the insect with contact insecticides.

Pupation occurs within chambers constructed by mature larvae, often leaving an emergence hole, covered with a thin layer of plant tissue that can be pushed open to allow the adult moth to emerge from the stem. D. saccharalis causes damage throughout the year, from sugarcane germination to harvesting time. In addition to killing shoots, the galleries in stems open the way for several pathogenic microorganisms which destroy the sugar stored in stalks (Smith et al., 1993).

In the Lower Rio Grande Valley of Texas, the Crambine stalkborers Eoreuma loftini (Dyar) and D. saccharalis damage 20% of sugarcane internodes annually (Legaspi et al., 1999). These authors also quantified the relationships between stalkborer damage and sugar yield and quality to estimate the monetary loss incurred at these levels of damage, with sugar losses of 108 g/kg cane.
In Cuba, losses attributed to *D. saccharalis* were estimated at 20% of sugar production (Gallo *et al.*, 1988). In Cuba, Barreto (1954) found a reduction of 0.02329% sucrose per 1% increase in bored internodes. In Mexico, Ruiz *et al.* (1968) estimated a loss of 1.68 lbs sucrose/ton sugarcane per 1% of increase in bored stalks.

In Argentina, one key factor that can decrease yields is sugarcane storage after harvest and before crushing in the mills (Romero *et al.*, 1990). This practice is common due to the diversity in the harvest and transport systems used and the dynamics of reception of the raw material at the mill. Cane harvested with traditional methods (not under green cane harvesting conditions) can be stored in Tucumán from 3 to 7 days, with weight losses up to 1.46% per storage day being reported, although this varied along the harvest season (Romero *et al.*, 1993). No data exist on the impact of sugarcane storage at different infestation levels of *D. saccharalis*.

The objective of this study was to evaluate the losses caused by *Diatraea saccharalis* on three sugarcane varieties throughout the harvesting season and the impact of sugarcane storage before crushing on yields.

**Materials and methods**

To assess losses, three major varieties at various infestation levels were analysed throughout the harvest season. Considering storage, one variety was sampled at various infestation levels during three periods of the harvest season, and sugar production measured at 1 day and 4 days after sampling.

Sugarcane samples were collected from Fronterita (Famailla Departament, Tucumán) sugar factory fields. Samples were weighed, juice was extracted and analysed and sugarcane pol %, brix and fibre were determined. All sucrose parameters were determined at the chemistry laboratories of Estación Experimental Agroindustrial Obispo Colombres.

During the 2005 harvest season, samples of three of the most important commercial varieties in the province: LCP 85-384 (65.2% of sugarcane planted area), TUCCP 77-42 (17.2%) and CP 65-357 (5.8%), were assayed. Sampling of each variety occurred in May, July, August and October at 45 days intervals. At each sampling date, six hundred stalks per variety were collected from the field and taken to the experimental mill.

The individual stalks were grouped by infestation level in order to obtain 5 infestation categories: unattacked cane, cane with 1–10%, 11–20%, 21–30%, and >40% of bored internodes. Then, for each category, three samples of 10 stalks each were taken to the laboratory to perform the corresponding quality analysis. To avoid excessive variability, the same plot was sampled at each sampling date.

In addition, three samplings were performed in June, August and October during the 2006 harvesting season, to evaluate the interaction of storage on losses to LCP 85-384 from *D. saccharalis* attack. Sampling dates were set every 45 days, as previously described. Each time, the same methodology as described above was followed in creating the different infestation level categories. However, in this case, six groups of 10 stalks each were made and arranged in two sets of 3 samples each. One set of samples was analysed the day after harvest, and the other, 4 days later.

The regression lines were estimated for sugar losses for each evaluated variety, LCP 85-384, TUCCP 77-42 and CP 65-357, in relation to the infestation level in cane. Differences among varieties were evaluated by means of ANOVA followed with Duncan’s multiple comparisons test. In addition, to evaluate regression slopes for LCP 85-384 cane with and without storage, R program (R development core team, 2009) lineal model was used.

**Results and discussion**

Figure 1 shows the observed sugar losses for the three varieties, combining all the harvest periods. Figures 2, 3 and 4 show sugar loss values, combining all harvest periods, for each variety.
Fig. 1—Sugar losses in relation to infestation percentage combining the three varieties analysed.

Fig. 2—Sugar loss in LCP 85-384.
Fig. 3—Sugar loss in TUCP 77-42.

Fig. 4—Sugar loss in CP 65-357.
Calculated sugar losses for all varieties and the four harvest dates of sugarcane are shown in Table 1. Reductions of 0.42% in stalk weight and 0.20% in pol of sugarcane for each 1% of attack were estimated, producing a 0.22% loss in factory yield for each % point of infestation, with a 620 to 650 g/t loss of sugar, depending on the variety.

**Table 1**—Weight, factory and sugar per stalk losses increase in relation to infestation levels. Data grouped for the three varieties studied and for all sampling dates;

<table>
<thead>
<tr>
<th>Infestation (%)</th>
<th>Weight decrease/stalk (%)</th>
<th>Factory yield losses (%)</th>
<th>Sugar loss/ t (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>5</td>
<td>2.14</td>
<td>1.12</td>
<td>3.23</td>
</tr>
<tr>
<td>10</td>
<td>4.28</td>
<td>2.24</td>
<td>6.42</td>
</tr>
<tr>
<td>15</td>
<td>6.42</td>
<td>3.35</td>
<td>9.56</td>
</tr>
<tr>
<td>20</td>
<td>8.56</td>
<td>4.47</td>
<td>12.65</td>
</tr>
<tr>
<td>25</td>
<td>10.70</td>
<td>5.59</td>
<td>15.69</td>
</tr>
<tr>
<td>30</td>
<td>12.84</td>
<td>6.71</td>
<td>18.68</td>
</tr>
<tr>
<td>40</td>
<td>17.12</td>
<td>8.94</td>
<td>24.53</td>
</tr>
<tr>
<td>50</td>
<td>21.40</td>
<td>11.18</td>
<td>30.18</td>
</tr>
</tbody>
</table>

The ANOVA analysis revealed significant differences among the different harvest times in the case of CP 65-357 in which sugar per stalk values diminished on successive dates (F = 2.86 P = 0.0396) (Table 2).

**Table 2**—Average (± SE) sugar (g) per stalk for each variety on four harvesting dates;

<table>
<thead>
<tr>
<th>Varieties</th>
<th>May</th>
<th>July</th>
<th>August</th>
<th>October</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP 65-357</td>
<td>92.8 ± 2.2</td>
<td>87.7 ± 3.2</td>
<td>84.3 ± 3.7</td>
<td>82.4 ± 3.6</td>
</tr>
<tr>
<td>LCP 85-384</td>
<td>89.6 ± 2.7</td>
<td>88.5 ± 2.5</td>
<td>89.9 ± 2.6</td>
<td>85.9 ± 3.5</td>
</tr>
<tr>
<td>TUC 77-42</td>
<td>87.3 ± 2.9</td>
<td>86.7 ± 3.1</td>
<td>86.1 ± 3.1</td>
<td>85.0 ± 3.9</td>
</tr>
</tbody>
</table>

Figures 5, 6, and 7 illustrate sugar losses in LCP 85-384 cane, in relation to infestation percentage and to storage after harvesting for 1 or 4 days before processing, considering three harvesting dates.
In Table 3, the relationship that exists between sugar loss (kg per tonne of cane) and infestation levels is shown. It is quite evident that storage has a very large incidence, increasing the losses, and also that those losses increase along the harvest season.

In June, sugar losses per tonne of cane and per percent of infestation amounted to 676 g when cane was stored. By contrast, cane without storage led to lower sugar losses: 626 g/t of cane and per percent of infestation. In August, sugar losses reached 723 g/t of cane and per percent of
infestation in the case of cane with storage, and 805 g in the case of cane without storage. Although sugar loss rates in cane with storage are lower than those in cane without storage, the total sugar loss in cane with storage is significantly higher as losses for cane without damage with 4 days storage begins with more than 50% losses. In October, losses were even greater with cane storage, reaching levels higher than 1.3–1.84 kg of sugar per tonne of cane and per percent of infestation. In the case of cane without storage, losses amounted to 1.2–1.7 kg of sugar per tonne of cane and percent of infestation. In this last case, there is a point at which losses do not increase, even though infestation goes on increasing.

| Table 3—Sugar losses (kg per tonne of cane) in relation to infestation percentages in cane, 1 or 4 days after harvest, considering different harvesting dates. |
|-----------------|----------------|----------------|----------------|----------------|
| Infestation (%) | 1 d storage | 4 d storage | 1 d storage | 4 d storage | 1 d storage | 4 d storage |
| 0               | 0.00        | 32.00        | 0.00         | 45.00        | 0.00         | 46.00        |
| 1–10            | 6.26        | 38.76        | 8.13         | 53.65        | 14.46        | 61.53        |
| 11–20           | 12.52       | 45.52        | 16.26        | 62.30        | 27.45        | 75.40        |
| 21–30           | 18.78       | 52.28        | 24.39        | 70.95        | 49.00        | 98.20        |
| 31–40           | 25.04       | 59.04        | 32.52        | 79.60        | 64.65        | 114.40       |
| 41–50           | 31.30       | 65.80        | 40.65        | 88.25        | 74.40        | 124.00       |

The analysis to compare the linear models obtained revealed that there were no significant differences between sugar loss regression slopes for cane with and without storage as they are parallel lines (P > 0.05, data not shown). By contrast, there were significant differences in the intercepts from the two categories (with and without storage).

In 2006, 11,451,000 t of cane were milled in the province, with an average of 7.61% *D. saccharalis* infestation (Salvatore et al., 2008). If we consider the lowest sugar loss, 620 g/t of cane, the estimated losses reached a total of 54,506 t sugar.

Data of losses of sugar per infestation percent obtained in this research are used by sugarcane growers to decide on harvesting dates. When harvested late, during warmer months, higher temperatures increase deterioration and thus sugar losses.

**Conclusions**

As *D. saccharalis* infestation percentage rises, sugar losses become higher. Sugar losses were much greater after 4 days post-harvest storage than after 1 day; this difference increased as harvest time advanced.

**Acknowledgments**

We thank Silvia Zossi for analysing samples and Adriana Manes for her assistance in the writing of the English version of this paper. Thanks are also due to two reviewers whose comments improved the manuscript.

**REFERENCES**


PERTES EN SUCRE CAUSÉES PAR LE FOREUR DE LA CANNE À SUCRE (DIATRAEA SACCHARALIS) À TUCUMÁN, ARGENTINE

Par

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MOTS CLÉS: Canne à Sucre, Diatraea saccharalis, Pertes.

Résumé
Le ravageur le plus dévastateur de la canne à sucre dans la Province de Tucumán est le foreur Diatraea saccharalis. Les galeries formées dans la tige sont des points d’entrées pour les pathogènes. Ces dégâts entraînent des pertes de poids de la tige, réduisent la qualité et la quantité de saccharose, et rendent difficile l’extraction du jus à l’usinage. Une étude a été entreprise afin de déterminer les pertes causées par le D saccharalis sur trois variétés de canne à sucre et sur la canne stockée avant l’usinage. Pendant la récolte de 2005, les observations faites sur les variétés industrielles, LCP 85-384, TUCCP 77-42 et CP 65-357 ont montré des pertes significatives au champ et à l’usine. Pour chaque 1% d’entremœufs attaqués, des réductions de 0,42% en poids de canne et 0,20% en pol ont été observées, causant des pertes de 0,22% à l’usinage. Dépendant de la variété, une chute en saccharose de 620 à 650 g/t de canne a été observée. En sus, la variété LCP 85-384 infestée par D. saccharalis a été échantillonnée en juin, août et octobre, pendant la récolte de 2006 pour évaluer l’effet du stockage. Une diminution en saccharose plus élevée après 4 jours de stockage post-récolte était constatée. La différence était plus marquée à mesure que la récolte progressait.
PERDIDAS DE AZÚCAR CAUSADAS POR EL GUSANO PERFORADOS DE LA CAÑA DE AZÚCAR (*DIATRAEA SACCHARALIS*) EN TUCUMÁN, ARGENTINA

Por

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PALABRAS CLAVE: Caña de Azúcar, *Diatraea saccharalis*, Pérdidas.

**Resumen**

El gusano perforador de la caña de azúcar, *Diatraea saccharalis*, es la principal plaga del cultivo de caña de azúcar en la Provincia de Tucumán. Las galerías producidas por las larvas son puerta de entrada a patógenos. Su efecto, genera pérdidas de peso en los tallos, reduce la calidad y el contenido de sacarosa y disminuye la extracción de jugo en la fábrica. El objetivo de este trabajo fue evaluar las pérdidas causadas por *Diatraea saccharalis* en tres variedades de caña de azúcar con y sin estacionamiento. Durante la zafra 2005, se realizaron ensayos en 3 variedades comerciales: LCP 85-384, TUCCP 77-42 y CP 65-357 y se determinó que el ataque provoca importantes pérdidas en el rendimiento cultural y fabril. Se encontraron reducciones por cada 1% de ataque de 0,42% en el peso de los tallos y de 0,20% en pol % caña, lo que produce pérdidas en el rendimiento fabril de 0,22% por punto de infestación, con una pérdida de azúcar de 620 a 650 g/t de caña, dependiendo de la variedad. Además, se realizaron ensayos con la variedad LCP 85-384 en tres diferentes fechas: Junio, Agosto y Octubre, durante la zafra 2006, se evaluó el efecto de las pérdidas por estacionamiento al ataque de *D. saccharalis*. Las pérdidas de azúcar fueron altas luego de 4 días de estacionamiento. Estas diferencias fueron mayores a medida que avanzaba la temporada de zafra.
EFFECTS OF INSECTICIDES ON MIGDOLUS FRYANUS WESTWOOD (COLEOPTERA: CERAMBYCIDAЕ) INFESTATIONS AND SUGARCANE YIELDS

By

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KEYWORDS: Saccharum, Insect Pests, Chemical Control.

Abstract
THE DESTRUCTION of root system by Migdolus fryanus Westwood (Coleoptera: Cerambycidaе) larvae reduces the yield and the longevity of sugarcane crops. Because of this damage, this insect is one of the most important pests of sugarcane in São Paulo State, Brazil. The present study was conducted to evaluate insecticide efficacy, when applied: a) at a depth of 40 cm, using ploughshares, during the land preparation prior to planting; b) in the furrows, at planting; and c) both at 40 cm and in the furrows. The experiment was carried out at the Santa Rita Sugar Mill, São Paulo, Brazil, using a randomised complete block design with 16 treatments (insecticides applied in the furrow and/or at 40 cm, and an untreated check) and 4 replicates. Sugarcane was planted in plots with five 15 m rows spaced 1.40 m apart, in March 2007. The pest populations were evaluated in periodic samplings and, on November 2007, when there was a flight of adults in the experimental area. The highest yields were observed in plots treated with endosulfan or fipronil. The treatments applied at 40 cm were more effective than the application of insecticides in the furrows. Fipronil or endosulfan applied at 40 cm, with or without additional insecticides in the furrows, increased yields by more than 25% over the untreated check.

Introduction
Migdolus fryanus (Coleoptera: Cerambycidaе) is one of the most important pests of sugarcane in São Paulo State, Brazil. The damage is caused by the larvae that attack both the roots and the stool, where they open large cavities.

As a result of roots and stools destruction, the plants are stunted, can be easily pulled out of the ground, and the stalks get dry and die. Thus, the crop stand, yield and longevity are drastically reduced (Dinardo-Miranda, 2008).

Current management strategies of infested areas involve several measures of control; however, none of them provide satisfactory control (Bento et al., 2004; Dinardo-Miranda, 2008). One of the most popular tactics is the mechanical destruction of infested ratoons, which kills M. fryanus larvae and pupae, due to mechanical damage and exposure to the sun and natural enemies (Arrigoni et al., 1986).

However, in many cases, mechanical destruction is not sufficient to reduce M. fryanus populations below the economic injury level and infested areas need insecticide treatment. The objective of this study was to evaluate the effects of insecticides, under two forms of application, on M. fryanus infestations and on sugarcane yields.
Materials and methods

An experiment was conducted in a sandy soil area, in São Paulo State, Brazil. Plots consisted of five 15-m-long furrows, spaced at 1.40 m, distributed in a random block design with four replicates.

Treatments are presented in Table 1. On 21 March 2007, the plots were demarcated in the experimental area and the insecticides were applied at a depth of 40 cm, in designated plots, with a spraying system placed behind the ploughshare discs. On 27 March 2007, the furrows were opened for each plot, respecting plot delimitations. After planting the variety RB867515, the insecticides were applied in the furrows, according to the treatments. Furrows were immediately closed after insecticide application.

Table 1—Insecticide treatments tested for *M. fryanus* control in sugarcane.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Insecticide applied at a depth of 40 cm (g/ha a.i.)</th>
<th>Insecticide applied in the furrows (g/ha a.i.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (Check)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Imidacloprid (1152)</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Fipronil (400)</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Endosulfan (4200)</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Imidacloprid (960)</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>Imidacloprid (960)</td>
<td>Imidacloprid (576)</td>
</tr>
<tr>
<td>G</td>
<td>Imidacloprid (960)</td>
<td>Fipronil (200)</td>
</tr>
<tr>
<td>H</td>
<td>Imidacloprid (960)</td>
<td>Endosulfan (2100)</td>
</tr>
<tr>
<td>I</td>
<td>Fipronil (320)</td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>Fipronil (320)</td>
<td>Imidacloprid (576)</td>
</tr>
<tr>
<td>K</td>
<td>Fipronil (320)</td>
<td>Fipronil (200)</td>
</tr>
<tr>
<td>L</td>
<td>Fipronil (320)</td>
<td>Endosulfan (2100)</td>
</tr>
<tr>
<td>M</td>
<td>Endosulfan (3500)</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>Endosulfan (3500)</td>
<td>Imidacloprid (576)</td>
</tr>
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<td>O</td>
<td>Endosulfan (3500)</td>
<td>Fipronil (200)</td>
</tr>
<tr>
<td>P</td>
<td>Endosulfan (3500)</td>
<td>Endosulfan (2100)</td>
</tr>
</tbody>
</table>

*M. fryanus* infestations were estimated on 20 June, 30 July, 3 October 2007 and 27 July 2008. For all samplings, a hole (0.50 m long, 0.50 m wide, 0.30 m deep) was opened in the first row of each plot. Soil and plant material were observed carefully to visualise biological forms of the pest and its damages.

The experiment was harvested on 27 July 2008. Stalk productivity was obtained by cutting and weighing the stalks from the second to fifth rows in each plot. The first row was not used to obtain the cane yield because many plants were destroyed during the sampling.

Prior to statistical analyses, *M. fryanus* population data were transformed (square root \(x + 1\)). Each sampling date was analysed separately. The analysis of variance was performed using SAS Statistical Analysis Systems software package (SAS Institute, 1995) and all means were compared by Tukey’s test. To verify the interference of the form of application and the insecticides, the analysis was conducted as a factorial experiment, in which one of the factors corresponded to form of application (at a depth of 40 cm or in the furrows) and the other to four insecticide regimes (no insecticide, fipronil, imidacloprid, endosulfan).

Results and discussion

High larval populations were found only on the 27 July 2008 sampling date (Table 2). In November 2007, there was a flight of *M. fryanus* into the experimental area. Because the larvae can
live for 2 years in the deep soil layers, up to 5-m deep, and adults emerge 3 to 4 months prior to a flight (Arrigoni, 1988), it is possible to conclude that the *M. fryanus* larvae were present in the experimental area, during the three first samplings, but were not detected because of their deep location.

When considering treatments individually, differences in *M. fryanus* infestations were only observed during the July 2008 sampling. Treatments with fipronil applied at a depth of 40 cm (treatments I, J and L) produced more than the untreated control (Table 2), suggesting that the treatment with fipronil in depth is important to improve the yield. Insecticides applied only in the furrows (treatments B, C and D) did not contribute to improved productivity.

When considering the treatments applied at a depth of 40 cm, regardless of the treatment applied in the furrows, plots treated with fipronil or endosulfan produced more cane than the check (without insecticides at 40 cm) and the treatment with imidacloprid (Table 3). Since other pests were not observed in the experimental area, these data suggest that both insecticides applied at a depth of 40 cm reduced the *M. fryanus* population and consequently increased yields. No differences in pest infestations were observed among treatments, because the insects were living and eating the roots in the deeper layers of the soil.

### Table 2—*Migdolus fryanus* populations as a function of sampling dates and yield

<table>
<thead>
<tr>
<th>Treatment</th>
<th><em>M. fryanus</em> (insects/hole)</th>
<th>Yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Jun 07</td>
<td>Jul 07</td>
</tr>
<tr>
<td>A. Untreated check</td>
<td>0 a</td>
<td>0 a</td>
</tr>
<tr>
<td>B. imidacloprid 1152 g/ha a.i in the furrows</td>
<td>0.3 a</td>
<td>0 a</td>
</tr>
<tr>
<td>C. fipronil furrows 400 g/ha a.i in the furrows</td>
<td>0.3 a</td>
<td>0 a</td>
</tr>
<tr>
<td>D. endosulfan furrows 4200 g/ha a.i in the furrows</td>
<td>0 a</td>
<td>0 a</td>
</tr>
<tr>
<td>E. imidacloprid 960 g/ha i.a. at 40 cm</td>
<td>0.3 a</td>
<td>0 a</td>
</tr>
<tr>
<td>F. imidacloprid 960 g/ha i.a. at 40 cm + imidacloprid 576 g/ha a.i in the furrows</td>
<td>0 a</td>
<td>0 a</td>
</tr>
<tr>
<td>G. imidacloprid 960 g/ha i.a. at 40 cm + fipronil 200 g/ha a.i in the furrows</td>
<td>0 a</td>
<td>0 a</td>
</tr>
<tr>
<td>H. imidacloprid 960 g/ha i.a. at 40 cm + endosulfan 2100 g/ha a.i in the furrows</td>
<td>0.3 a</td>
<td>0 a</td>
</tr>
<tr>
<td>I. fipronil 320 g/ha i.a. at 40 cm</td>
<td>0 a</td>
<td>0 a</td>
</tr>
<tr>
<td>J. fipronil 320 g/ha i.a. at 40 cm + imidacloprid 576 g/ha a.i in the furrows</td>
<td>0 a</td>
<td>0 a</td>
</tr>
<tr>
<td>K. fipronil 320 g/ha i.a. at 40 cm + fipronil 200 g/ha a.i in the furrows</td>
<td>0 a</td>
<td>0 a</td>
</tr>
<tr>
<td>L. fipronil 320 g/ha i.a. at 40 cm + endosulfan 2100 g/ha a.i in the furrows</td>
<td>0 a</td>
<td>0 a</td>
</tr>
<tr>
<td>M. endosulfan 3500 g/ha i.a. at 40 cm</td>
<td>0 a</td>
<td>0 a</td>
</tr>
<tr>
<td>N. endosulfan 3500 g/ha i.a. at 40 cm + imidacloprid 576 g/ha a.i in the furrows</td>
<td>0.3 a</td>
<td>0.3 a</td>
</tr>
<tr>
<td>O. endosulfan 3500 g/ha i.a. at 40 cm + fipronil 200 g/ha a.i in the furrows</td>
<td>0 a</td>
<td>0.3 a</td>
</tr>
<tr>
<td>P. endosulfan 3500 g/ha i.a. at 40 cm + endosulfan 2100 g/ha a.i in the furrows</td>
<td>0.3 a</td>
<td>0 a</td>
</tr>
<tr>
<td>F value</td>
<td>0.67</td>
<td>1.11</td>
</tr>
<tr>
<td>P value</td>
<td>0.79</td>
<td>0.14</td>
</tr>
<tr>
<td>CV (%)</td>
<td>12.1</td>
<td>7.6</td>
</tr>
</tbody>
</table>

Means followed by the same letters in columns are similar by Tukey’s test (P < 0.05).
Table 3—*Migdolus fryanus* populations at sampling dates and yield, as a function of the treatment made at a depth of 40 cm.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>M. fryanus (insects/hole)</th>
<th>Yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Jun 07</td>
<td>Jul 07</td>
</tr>
<tr>
<td>Check (no insecticides at 40 cm)</td>
<td>0.1 a</td>
<td>0 a</td>
</tr>
<tr>
<td>imidacloprid</td>
<td>0 a</td>
<td>0 a</td>
</tr>
<tr>
<td>fipronil</td>
<td>0.1 a</td>
<td>0 a</td>
</tr>
<tr>
<td>endosulfan</td>
<td>0.1 a</td>
<td>0.1 a</td>
</tr>
<tr>
<td><strong>F value</strong></td>
<td>0.42</td>
<td>1.05</td>
</tr>
<tr>
<td><strong>P value</strong></td>
<td>0.89</td>
<td>0.16</td>
</tr>
<tr>
<td><strong>CV (%)</strong></td>
<td>11.0</td>
<td>6.9</td>
</tr>
</tbody>
</table>

Means followed by the same letters in columns are similar by Tukey’s test (P < 0.05).

When considering treatments applied in the furrows, regardless of treatment applied at a depth of 40 cm, no differences in pest populations and sugarcane yield were observed (Table 4). These observations suggest that, for the management of *M. fryanus* infested areas, fipronil or endosulfan applications into the soil profile are more effective than the applications in the furrows.

Table 4—*Migdolus fryanus* populations at sampling dates and yield, as a function of the treatment applied in the furrows.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>M. fryanus (insects/hole)</th>
<th>Yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Jun 07</td>
<td>Jul 07</td>
</tr>
<tr>
<td>Check (no insecticides on the furrows)</td>
<td>0.1 a</td>
<td>0 a</td>
</tr>
<tr>
<td>imidacloprid</td>
<td>0.1 a</td>
<td>0.1 a</td>
</tr>
<tr>
<td>Fipronil</td>
<td>0.1 a</td>
<td>0.1 a</td>
</tr>
<tr>
<td>Endosulfan</td>
<td>0.1 a</td>
<td>0 a</td>
</tr>
<tr>
<td><strong>F value</strong></td>
<td>0.27</td>
<td>1.94</td>
</tr>
<tr>
<td><strong>P value</strong></td>
<td>0.84</td>
<td>0.14</td>
</tr>
<tr>
<td><strong>CV (%)</strong></td>
<td>11.0</td>
<td>6.9</td>
</tr>
</tbody>
</table>

Means followed by the same letters in columns are similar by Tukey’s test (P < 0.05).

In conclusion, our data suggest that insecticide treatments applied at a depth of 40 cm were more effective than the application of insecticides in the planting furrows. Fipronil or endosulfan applied at this depth, with or without insecticides in the furrows, increased the yield by more than 25% over the untreated check.

REFERENCES


EFFETS DES TRAITEMENTS INSECTICIDES SUR L’INFESTATION
DE MIGDOLUS FRYANUS WESTWOOD (COLEOPTERA:
CERAMBYCIDAE) ET SUR LE RENDEMENT DE LA CANNE À SUCRE

Par

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MOTS CLÉS: Saccharum,
Ravageurs, Lutte Chimique.

Résumé
LA DESTRUCTION du système radiculaire par les larves de Migdolus fryanus Westwood (Coleoptera :
Cerambycidae) occasionne une baisse de rendement et affecte la pérennité de la canne à sucre. En
raison de ces dégâts, ce ravageur est un des plus importants de la canne à sucre dans l’État de São
Paulo au Brésil. L’étude présente a été élaborée afin d’évaluer l’efficacité des insecticides appliqués
a) à une profondeur de 40 cm en utilisant des socs, pendant la préparation du sol avant la plantation;
b) dans les sillons à la plantation et c) par les deux méthodes à la fois. L’expérimentation a été
effectuée à Santa Rita Sugar Mill, São Paulo au Brésil, en adoptant un dispositif de blocs
complètement randomisés de 16 traitements (insecticides enfouis à 40 cm et/ou appliqués dans les
sillons, et un témoin non-traité) avec 4 répétitions. En mars 2007, la canne a été plantée dans des
parcelles de cinq lignes de 15 m et espacées de 1,40 m. La population du ravageur a été évaluée en
faisant des échantillonnages périodiques dont en novembre 2007, lors des vols des adultes dans la
parcelle expérimentale. Les rendements les plus élevés ont été obtenus dans les parcelles traitées à
l’endosulfan ou au fipronil. L’application d’insecticide à 40 cm de profondeur a été plus efficace
que le traitement dans les sillons. Le fipronil ou l’endosulfan enfoui à 40 cm, avec ou sans
traitement additionnel d’insecticide dans les sillons, a augmenté des rendements par plus de 25%
au-dessus du témoin non-traité.
EFECTOS DE INSECTICIDAS EN LAS INFESTACIONES DE *MIGDOLUS FRIANUS* WESTWOOD (COLEÓPTERA: CERAMBYCIDAE) Y EN LA PRODUCCIÓN DE CAÑA DE AZÚCAR

Por

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PALABRAS CLAVE: Saccharum, Plagas de Insectos, Control Químico.

Resumen

LA DESTRUCCIÓN del sistema de raíces por las larvas de *Migdolus fryanus* Westwood (Coleoptera: Cerambycidae) disminuye la producción y longevidad de los cultivos de caña de azúcar. Debido a este daño, el insecto es una de las plagas más importantes de la caña de azúcar en el Estado de San Paulo, Brasil. El presente estudio se realizó para evaluar la eficacia de los insecticidas, cuando se aplican: a) a una profundidad de 40 cm, usando arados, durante la preparación de la tierra antes de sembrar; b) en los surcos, en la siembra, y c) tanto a 40 cm como en los surcos. El experimento se llevó a cabo en el Ingenio Santa Rita, San Paulo, Brasil, utilizando un diseño de bloques completos al azar con 16 tratamientos (insecticidas aplicados en el surco y/o 40 cm, y un control sin tratar) y cuatro repeticiones. La caña de azúcar se sembró en parcelas con cinco surcos de 15 m de largo, espaciados a 1.40 m, en marzo de 2007. Las poblaciones de la plaga se evaluaron en los muestreos periódicos y en noviembre de 2007, cuando hubo un vuelo de adultos en el área experimental. Las producciones más altas se observaron en las parcelas tratadas con Endosulfán o el Fipronil. Los tratamientos aplicados a 40 cm fueron más eficaces que las aplicaciones de insecticidas en los surcos. El Fipronil o el Endosulfán aplicado a 40 cm, con o sin insecticidas adicionales en los surcos, aumentó las producciones en más del 25% con respecto a la a los testigos sin tratar.
EFFECT OF INSECTICIDES APPLIED AT SUGARCANE PLANTING ON SPHENOPHORUS LEVIS VAURIE (COLEOPTERA; CURCULIONIDAE) CONTROL AND ON THE YIELD OF FIRST TWO HARVESTS

By

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KEYWORDS: Saccharum, Sphenophorus levis, Insect Pests, Chemical Control, Management.

Abstract
RECENTLY, the occurrence of sugarcane fields severely damaged by Sphenophorus levis Vaurie (Coleoptera; Curculionidae) has increased in the Central-South region, the main area where sugarcane is grown in Brazil. The pest management program includes mechanical destruction of infested ratoons, which often is not enough to maintain the populations below economic injury level. The use of insecticides is therefore necessary. The objective of the present work was to evaluate the effect of insecticides applied at sugarcane planting on the pest control and on the yield of the first two harvests. Three experiments were conducted as random block designs with six replicates. In addition to an untreated check, the following treatments were evaluated: carbofuran 2100 g/ha a.i., fipronil 200 g/ha a.i., carbofuran 2100 g/ha a.i. + fipronil 200 g/ha a.i., imidacloprid 960 g/ha a.i., thiamethoxam 375 g/ha a.i. and bifenthrin 250 g/ha a.i.. S. levis infestations and associated plant injury were evaluated by periodic samplings. Yield data were recorded for the first two harvests. No differences between the treatments and the untreated check in relation to pest population and injury were observed. However, the treatments with fipronil, imidacloprid and thiamethoxam were associated with significant yield increases for both harvests. Considering the two harvests, these increases reached 52.2 to 69.0 t/ha or 25% of yield, suggesting that these treatments can be useful in an integrated management program.

Introduction
Recently, the occurrence of sugarcane fields severely damaged by Sphenophorus levis Vaurie (Coleoptera; Curculionidae) has increased in the Central-South region, the main area where sugarcane is grown in Brazil (Dinardo-Miranda, 2000). Damage is caused by the larvae that bore into the stool and, sometimes, the first basal internode, where they open large cavities (Precetti and Arrigoni, 1990). As a result of stool destruction the plants are stunted; the shoots become dry and die. The stand, the yield and the longevity of the crop are drastically reduced (Dinardo-Miranda, 2008).

The management of infested areas involves the mechanical destruction of infested ratoons, killing larvae and pupae of the pest, as well as the use of insecticides at planting.

Despite the importance of S. levis to sugarcane in Brazil, few studies on the efficiency of insecticidal control have been conducted. The objective of this study was to evaluate the effect of insecticides on S. levis control and on the yield at the first two harvests.

Materials and methods
Three experiments were conducted in São Paulo State, Brazil. Experiments 1 and 2 were planted on 15 February 2005 and 28 March 2005, respectively, with the sugarcane variety SP81-3250. Experiment 3 was planted on 11 May 2005 with RB867515. Plots consisted of six 10-m-long furrows, spaced at 1.50 m, distributed in a random block design with six replicates.
In experiment 1, treatments were: a) untreated check, b) carbofuran 2100 g/ha a.i., c) fipronil 200 g/ha a.i., d) carbofuran 2100 g/ha a.i. + fipronil 200 g/ha a.i., e) imidacloprid 960 g/ha a.i., f) thiamethoxam 375 g/ha a.i. and g) bifenthrin 250 g/ha a.i. The same treatments were tested in experiment 2 (except treatment d) and experiment 3 (except treatment b). Treatments were applied in the furrows, before closing them.

*S. levis* infestations and injury were evaluated in plant cane plots 2, 4, 6 and 8 months after planting, except in experiment 3, where the last sampling was not conducted. For ratoon cane sampling, data were collected 3 and 5 months after the first harvest.

For all samplings, a hole (0.50 m long, 0.50 m wide, 0.30 m deep) was opened in the first furrow of each plot. Soil and plant material were observed carefully to determine *S. levis* abundance and the total and injured shoots were counted to obtain the percentage of injured shoots.

Yields were determined for the first two harvests: 13 May 2006 and 26 May 2007 for experiment 1; 10 July 2006 and 4 December 2007 for experiment 2; and 22 May 2006 and 22 May 2007 for experiment 3, by cutting and weighing the stalks from the second to sixth rows in each plot. The first row was not used to obtain the yield because many plants were destroyed during the sampling.

Prior to statistical analyses, *S. levis* population data were transformed to square root ($x + 1$) and injury data to arcsine (square root [$\sqrt{x/100}$]). Each sampling date was analysed separately.

The analysis of variance was performed using SAS Statistical Analysis Systems software package (SAS Institute, 1995) and the treatment means were compared to untreated check means by Dunnett’s test. The experiment group analysis was also conducted using SAS software package, considering three experiments and seven treatments.

**Results and discussion**

The highest infestations and injury were observed in ratoons (Table 1). The destruction of infested crop residues and tillage prior to planting contributed to pest population reduction, due to mechanical damages and exposure to the sun and natural enemies of the larvae and pupae (Pizzano *et al.*, 1987). After planting, soil disturbance is minimised, allowing *S. levis* populations to increase.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Plant cane</th>
<th>Ratoon</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 months</td>
<td>4 months</td>
</tr>
<tr>
<td></td>
<td>SI</td>
<td>D</td>
</tr>
<tr>
<td>Untreated check</td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>Carbofuran</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fipronil</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Carbofuran + Fipronil</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Imidacloprid</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Thiamethoxam</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Bifenthrin</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>F value</td>
<td>1.00</td>
<td>1.18</td>
</tr>
<tr>
<td>P value</td>
<td>0.44</td>
<td>0.33</td>
</tr>
<tr>
<td>C.V. (%)</td>
<td>6.8</td>
<td>9.6</td>
</tr>
</tbody>
</table>

Means within columns marked with (*) differ from untreated check (Dunnett’s test, $P < 0.10$).
No differences in *S. levis* infestations and injury were observed between insecticide treated and untreated check plots, except four months after planting, when the bifenthrin treatment presented a higher percentage of shoot damaged than the check (Table 1).

For the plant cane harvest, all insecticide treatments were associated with increased yields. For the second harvest, fipronil, fipronil + carbofuran, imidacloprid and thiamethoxam plots had greater yields than untreated check plots (Table 2).

Carbofuran seems not as effective as fipronil, imidacloprid or thiamethoxam because, in plant cane, this product showed the smallest yield increase, while, in the ratoon cane, it did not contribute to increase the yield.

Since plots treated with fipronil showed the same level of increase as the plots treated with fipronil + carbofuran, it can be argued that effects on yield, in the ratoon cane, were due to fipronil.

**Table 2**—Yields (t/ha) observed at first and second harvest, as a function of treatments and total increase of yield of each treatment in relation to check (Δ) (means of three experiments).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>1&lt;sup&gt;st&lt;/sup&gt; Harvest</th>
<th>2&lt;sup&gt;nd&lt;/sup&gt; Harvest</th>
<th>1&lt;sup&gt;st&lt;/sup&gt;+ 2&lt;sup&gt;nd&lt;/sup&gt; Harvests</th>
<th>Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated check</td>
<td>141.8</td>
<td>134.4</td>
<td>276.2</td>
<td></td>
</tr>
<tr>
<td>Carbofuran</td>
<td>154.1*</td>
<td>139.4</td>
<td>295.5</td>
<td>17.3</td>
</tr>
<tr>
<td>Fipronil</td>
<td>166.2*</td>
<td>167.6*</td>
<td>333.8*</td>
<td>57.6</td>
</tr>
<tr>
<td>Carbofuran + fipronil</td>
<td>172.2*</td>
<td>173.0*</td>
<td>345.2*</td>
<td>69.0</td>
</tr>
<tr>
<td>Imidacloprid</td>
<td>170.8*</td>
<td>167.0*</td>
<td>337.8*</td>
<td>61.6</td>
</tr>
<tr>
<td>Thiamethoxam</td>
<td>172.0*</td>
<td>160.4*</td>
<td>332.4*</td>
<td>56.2</td>
</tr>
<tr>
<td>Bifenthrin</td>
<td>156.2*</td>
<td>145.7</td>
<td>301.9</td>
<td>25.7</td>
</tr>
<tr>
<td>F value</td>
<td>11.46</td>
<td>6.91</td>
<td>13.01</td>
<td></td>
</tr>
<tr>
<td>P value</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>C.V. (%)</td>
<td>8.2</td>
<td>7.3</td>
<td>5.9</td>
<td></td>
</tr>
</tbody>
</table>

Means within columns marked with (*) differ from untreated check (Dunnett’s test, P < 0.10).

There was no evident correlation between pest population and yield, because no differences were observed among the treatments in relation to pest population. The sampling method may not have been precise enough to evaluate the pest population. It is evident that the insecticides were not very efficient, probably because they tend to move to the stalks and leaves, staying in low concentration in plant and ratoon stool, where *S. levis* larvae feed. Despite the fact the insecticides were not efficient in controlling *S. levis*, they increased yields.

Although some insecticides like thiamethoxam and imidacloprid contribute to yield increases ranging from 4 to 8 t/ha when applied in fields with low pest pressure, due to their direct effect on the plants, increases like those observed in these experiments can not be attributed to this effect.

Since others pests were not found in the experimental areas, the lower yields observed in untreated plots, compared with treated plots, can be attributed to *S. levis* populations. In fact, commercial areas infested with 0.5 *S. levis* per hole show clear symptoms of the pest attack, like stand and yield drastically reduced.

On average, treatments with fipronil, fipronil + carbofuran, imidacloprid and thiamethoxam applied at planting contributed to yield increases ranging from 56.2 to 69.0 t/ha for the first two harvests combined, suggesting that these insecticides can be useful in an integrated management program.

**REFERENCES**

**APPLICATION DES INSECTICIDES À LA PLANTATION CONTRE LE SPHENOPHORUS LEVIS VAURIE (COLEOPTERA; CURCULIONIDAE) ET SUR EFFET SUR LE RENDEMENT DES DEUX PREMIÈRES RÉCOLTES DE LA CANNE À SUCRE**

Par

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**MOTS CLÉS: Saccharum, Sphenophorus levis, Ravageurs, Lutte Chimique, Gestion des Ravageurs.**

**Résumé**

RECENTEMENT, la fréquence des champs de canne à sucre sévèrement endommagés par le *Sphenophorus levis* Vaurie (Coleoptera; Curculionidae) a augmenté dans la région méridionale-sud, le partie la plus importante pour la culture de la canne au Brésil. Le programme de gestion du ravageur inclut la destruction mécanique des repousses infestées, qui souvent n’est pas suffisant pour maintenir la population en dessous du seuil de nuisibilité économique. Le recours aux insecticides est donc nécessaire. Le but de la présente étude est d’évaluer l’effet des insecticides appliqués à la plantation de la canne sur le ravageur et sur le rendement obtenu pendant les deux premières récoltes. Trois essais ont été entrepris en adoptant un dispositif de blocs randomisés avec six répétitions. En sus du témoin non-traité, les traitements suivants ont été évalués: carbofuran à 2100 g/ha m.a., fipronil à 200 g/ha m.a., carbofuran à 2100 g/ha m.a. + fipronil à 200 g/ha m.a., imidacloprid à 960 g/ha m.a., thiamethoxam à 375 g/ha m.a. and bifenthrin à 250 g/ha m.a. Les infestations de *S. levis* et les dégâts occasionnés ont été évalués grâce à un échantillonnage périodique. Les données de rendements pour les premières récoltes ont été recueillies. Aucune différence n’a été observée entre les parcelles traitées et celles non-traitées par rapport à l’infestation et les dégâts. Cependant, les traitements au fipronil, à l’imidacloprid et au thiamethoxam ont entraîné une augmentation significative du rendement pour les deux récoltes. Effectivement, les augmentations ont atteint 52.2 à 69.0 t/ha ou 25% de rendement, suggérant que ces traitements puissent être utiles dans un programme de lutte intégrée.
EFECTO DE LOS INSECTICIDAS APLICADOS DURANTE LA SIEMBRA EN EL CONTROL DE SPHENOPHORUS LEVIS VAURIE (COLEOPTERA: CURCULIONIDAE) Y EN LA PRODUCCIÓN DE CAÑA EN LOS DOS PRIMEROS CORTES

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PALABRAS CLAVE: Saccharum, Sphenophorus levis, Control de Plagas, Control Químico, Manejo.

Resumen
RECENTEMENTE se ha observado el aumento de campos de caña de azúcar severamente afectados por Sphenophorus levis Vaurie (Coleoptera, Curculionidae) en la región Centro-Sur, principal área donde se cultiva caña de azúcar en el Brasil. El programa de manejo de la plaga incluye la destrucción mecánica de retoños infestados, lo que a menudo no es suficiente para mantener las poblaciones del insecto por debajo del nivel de daño económico, siendo necesario el uso de insecticidas. El objetivo del presente trabajo fue evaluar el efecto de los insecticidas aplicados durante la siembra de caña en el control de la plaga y determinar la producción de los dos primeros cortes. Se realizaron tres experimentos con diseños de bloques al azar y seis répeticiones. Además del control sin tratar, se evaluaron los siguientes tratamientos: Carbofuran, 2100 g/ha de ingrediente activo (i.a.), Fipronil, 200 g/ha de i.a., Carbofuran, 2100 g/ha de i.a.+ Fipronil, 200 g/ha de i.a., Imidacloprid, 960 g/ha de i.a., Tiametoxam, 375 g/ha de i.a. y bifentrina, 250 g/ha de i.a. Se evaluaron las infestaciones y daños asociados con S. levis mediante muestreos periódicos. Los resultados de producción se registraron durante los dos primeros cortes. No se observaron diferencias entre los tratamientos y el control sin tratar en relación con la población de la plaga y el daño causado. Sin embargo, los tratamientos con Fipronil, Imidacloprid y Tiametoxam se tuvieron aumentos significativos de producción de caña, en ambos cortes. Teniendo en cuenta los dos cortes, los aumentos fueron de 52.2 a 69.0 t/ha o aumento de 25% en la producción, lo que sugiere que estos tratamientos pueden tener utilidad en un programa de manejo integral.
SPATIAL DISTRIBUTION OF SUGARCANE SPITTLEBUG, 
*MAHANARVA FIMBRIOLATA*, IN SUGARCANE FIELDS

By

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KEYWORDS: Saccharum, Sugarcane, Pests, Sampling.

Abstract

SUGARCANE spittlebug, *Mahanarva fimbriolata* (Stål) (Hemiptera: Cercopidae), is one of the most important pests of sugarcane in the Central-Southern region of Brazil. Information on its spatial distribution in sugarcane fields is important for the development of sampling plans, aimed at their application in integrated management programs. We studied the spatial distribution of *M. fimbriolata* in 10 mechanically harvested green cane fields in Catanduva, São Paulo State, Brazil. In each field of 1.41 ha, 150 samples were collected within a rectangular grid measuring 10 × 10.5 m, between 27 December 2007 and 1 November 2008. The Morisita index was significantly > 1 for eight fields, indicating that, in each of these fields, *M. fimbriolata* has an aggregated spatial distribution and this pattern was not affected by the infestation level. In two fields, *M. fimbriolata* occurred at random. Geostatistical analysis allowed the construction of contour maps through kriging interpolation using the spatial dependence expressed in the semivariograms for five fields. For the other three fields where *M. fimbriolata* has aggregated spatial distribution, it was not possible to construct population maps using kriging interpolation because the distance between sampling points was too large to detect spatial dependence. For the cases where the maps could be constructed, the ranges varied from 23 to 55 m and, using this information, we estimated that it was necessary to sample 6 points/ha to adequately estimate the insect population.

Introduction

Sugarcane spittlebug, *Mahanarva fimbriolata* (Stål) (Hemiptera: Cercopidae), is one of the most important pests of sugarcane in the Central-Southern region of Brazil. Besides noticeably reducing stalk productivity, it causes alterations in the quality of the sugarcane, reducing stalk sugar content and increasing fibre content.

Losses also extend to milling processes, because dead and dry stalks resulting from the attack of the pest reduce the milling capacity as stalks are often cracked and deteriorated, and contaminants make sugar recovery difficult and inhibit fermentation (Dinardo-Miranda, 2008).

To develop sampling plans for application in integrated management programs, we need to know this important pest’s spatial distribution in sugarcane fields. Thus, we sought to characterise the spatial distribution of *M. fimbriolata* in sugarcane fields to provide guidance for sampling procedures.

Materials and methods

We studied the spatial distribution of *M. fimbriolata* in 10 mechanically harvested green cane fields in Catanduva, São Paulo State, Brazil. In each field of 1.41 ha, 150 samples were
collected within a rectangular grid measuring 10 × 10.5 m, between 27 December 2007 and 1 January 2008, when the ratoons were 4–5 months old. Each sample was represented by 2 m of furrow, where nymphs and occasional adults present on the roots were counted. To visualise the insects on the roots, we carefully pushed away the trash from the sugarcane furrow with a wooden stick and removed the insects from the root region, in the subsurface soil layer.

Data were initially analysed by descriptive statistics of mean, standard deviation, coefficient of variation, maximum value, minimum value, skewness and kurtosis. The Morisita index* was calculated in accordance with Bubenicek and Haas (1969). After this, geostatistical analyses were run using semivariograms and kriging interpolation to construct maps.

The semivariogram analyses were conducted using the GEOSTAT software (Vieira et al., 1983). Based on the models fitted to the semivariograms, the jackknifing test was used to verify whether the estimates of semivariogram parameters were adequate and to estimate the number of neighbours that should be used in kriging (Vieira, 2000).

Once the parameters for the model were confirmed and the adequate numbers of neighbours were estimated, values were interpolated for the locations where they were not measured, by the kriging method, using the GEOSTAT software (Vieira et al., 1983). The kriging-estimated values were used in Surfer software (Golden Software, 1999) to construct the maps.

**Results and discussion**

In all fields, *M. fimbriolata* population presented high coefficient of variation, with great differences between the maximum and the minimum value (Table 1). A similar observation was reported by Dinardo-Miranda *et al.* (2007), who also worked in São Paulo State, with the variety RB855536.

The Morisita index was significantly greater than 1 for eight fields, indicating that in these fields the *M. fimbriolata* has aggregated spatial distribution and this pattern was not affected by the infestation level.

In two fields, *M. fimbriolata* occurred at random. Dinardo-Miranda *et al.* (2007) and Stingel (2005), working in several fields in São Paulo State, observed in all studied areas that *M. fimbriolata* presented aggregated distribution patterns.

<table>
<thead>
<tr>
<th>Area</th>
<th>Mean (insects/2 m)</th>
<th>Minimum value</th>
<th>Maximum value</th>
<th>Coefficient of variation (%)</th>
<th>Variance</th>
<th>Skewness</th>
<th>Kurtosis</th>
<th>Morisita index</th>
<th>F0**</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16.1</td>
<td>0</td>
<td>34</td>
<td>37.6</td>
<td>36.77</td>
<td>– 0.06</td>
<td>1.13</td>
<td>1.08*</td>
<td>2.28</td>
</tr>
<tr>
<td>2</td>
<td>15.4</td>
<td>0</td>
<td>31</td>
<td>42.1</td>
<td>42.08</td>
<td>– 0.15</td>
<td>– 0.10</td>
<td>1.11*</td>
<td>2.73</td>
</tr>
<tr>
<td>3</td>
<td>5.1</td>
<td>0</td>
<td>24</td>
<td>136.8</td>
<td>48.71</td>
<td>1.06</td>
<td>– 0.15</td>
<td>2.67*</td>
<td>9.55</td>
</tr>
<tr>
<td>4</td>
<td>4.5</td>
<td>0</td>
<td>19</td>
<td>124.6</td>
<td>31.57</td>
<td>0.82</td>
<td>– 0.72</td>
<td>2.32*</td>
<td>6.99</td>
</tr>
<tr>
<td>5</td>
<td>4.5</td>
<td>0</td>
<td>21</td>
<td>127.7</td>
<td>33.18</td>
<td>0.86</td>
<td>– 0.60</td>
<td>2.40*</td>
<td>7.35</td>
</tr>
<tr>
<td>6</td>
<td>2.6</td>
<td>0</td>
<td>13</td>
<td>139.8</td>
<td>13.33</td>
<td>1.01</td>
<td>– 0.45</td>
<td>2.56*</td>
<td>5.10</td>
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<td>5</td>
<td>34</td>
<td>27.1</td>
<td>19.24</td>
<td>0.99</td>
<td>1.92</td>
<td>1.02</td>
<td>1.18</td>
</tr>
<tr>
<td>8</td>
<td>23.5</td>
<td>0</td>
<td>73</td>
<td>84.1</td>
<td>389.46</td>
<td>0.22</td>
<td>– 0.95</td>
<td>1.66*</td>
<td>16.59</td>
</tr>
<tr>
<td>9</td>
<td>24.2</td>
<td>0</td>
<td>35</td>
<td>21.8</td>
<td>27.92</td>
<td>– 1.76</td>
<td>5.40</td>
<td>1.01</td>
<td>1.15</td>
</tr>
<tr>
<td>10</td>
<td>47.6</td>
<td>0</td>
<td>100</td>
<td>43.6</td>
<td>431.89</td>
<td>0.15</td>
<td>– 0.90</td>
<td>1.17*</td>
<td>9.06</td>
</tr>
</tbody>
</table>

*Morisita index = Measures the distribution of a field sampling.
* = significant at 5% and ** = Value of F,

Among the 10 calculated semivariograms, those corresponding to areas 1, 4, 7, 8 and 9 exhibited a ‘pure nugget’ effect* (Table 2). In relation to areas 7 and 9, this was because the pest, in these fields, occurred at random, according to the Morisita index.

For the other areas (1, 4 and 8), the distance between sampling points was too large to allow the detection of a spatial dependence between them.
### Table 2

<table>
<thead>
<tr>
<th>Area</th>
<th>Semivariogram parameters (reduced errors)</th>
<th>Jack knifing parameters</th>
<th>$r^2$</th>
<th>$C_0/(C_0+C_1)$</th>
<th>Area $^1$ (m$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$C_0$</td>
<td>$C_1$</td>
<td>$a$ (m)</td>
<td>mean</td>
<td>variance</td>
</tr>
<tr>
<td>1</td>
<td>25</td>
<td>20</td>
<td>55</td>
<td>0.0092</td>
<td>0.9310</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>40</td>
<td>32</td>
<td>0.0019</td>
<td>1.0508</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>5.4</td>
<td>40</td>
<td>0.0029</td>
<td>1.0080</td>
</tr>
<tr>
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<td>20</td>
<td>11</td>
<td>50</td>
<td>0.0037</td>
<td>1.0100</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>27</td>
<td>23</td>
<td>0.0010</td>
<td>0.9585</td>
</tr>
</tbody>
</table>

$^1$ Area calculated by $\Pi r^2$, where $\Pi = 3.1416$ and $r = a$.

Pure nugget effect – Value of semivariance when the null distance.

The spherical model was best fitted to the semivariograms of data for areas 2, 3, 5, 6 and 10 (Figure 1, Table 2). Although the $r^2$ values were low, the parameters estimated for the spherical model ($C_0$, $C_1$, $a$) were endorsed by the jack knifing test, since the mean values for the reduced errors were near zero and the values for the variance of reduced errors were near 1 (Table 2). Maps showing the spatial distribution of the insects in areas 2, 3, 5, 6 and 7 are shown in Figure 2.

Fig. 1—Semivariograms for populations of *Mahanarva fimbriolata* in areas 2, 3, 5, 6 and 10. Numbers in parenthesis are nugget effect value ($C_0$), $C_1$ and range ($a$) of spherical model (Sph).
The portion of variability attributed to spatial dependence, given by the $C_0/(C_0 + C_1)$ ratio, ranged from 0.20 to 0.60 (Table 2), indicating a strong or a moderate spatial dependence among samples (Cambardella et al., 1994). The range ($a$), representing the distance at which there is spatial dependence between samples, varied from 23 to 55 m. These data allowed us to estimate that the spittlebug aggregation area ($A = \pi r^2$, where $r = a$), in these fields, varied from 1.662 m$^2$ to
9.503 m², suggesting that 6 and 1 sampling points per hectare would be necessary to obtain a reliable estimate for the pest population in areas 10 and 2, respectively.

Dinardo-Miranda et al. (2007), working with *M. fimbriolata* in sugarcane fields, also found moderate spatial dependence among samples. In that study, the ranges varied from 33 to 56 m allowing those authors to conclude that it was necessary to sample 3 points/ha to adequately estimate the insect population. Using this information, we estimated that it was necessary to sample 6 points/ha to adequately estimate the insect population.

**REFERENCES**


DISTRIBUTION SPATIALE DE LA CICADELLE ÉCUMEUSE DE LA CANNE SUCRE, MAHANARVA FIMBRIOLATA, DANS LES CHAMPS DE CANNE À SUCRE

Par

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MOTS CLÉS: Saccharum, Canne à Sucre, Ravageurs, Échantillonnage, Cicadelle Écumeuse.

Résumé

La cicadelle écumeuse de la canne à sucre, Mahanarva fimbriolata (Stål) (Hemiptera: Cercopidae), est un des plus importants ravageurs de la région méridionale-sud du Brésil. Les informations sur sa distribution spatiale dans les champs de canne à sucre sont importantes pour l’élaboration des plans de sondages et leur utilisation dans les programmes de gestion intégrée. Nous avons étudié la distribution spatiale de M. fimbriolata dans 10 champs recolts mécaniquement en vert à Catanduva, État de São Paulo au Brésil. Pour chaque champ de 1.41 ha, 150 échantillons ont été prélevés à l’intérieur d’une grille rectangulaire de 10 × 10.5 m, entre le 27 décembre 2007 et 1er novembre 2008. L’index de Morisita était significativement supérieur à 1 pour huit champs, démontrant que M. fimbriolata avait une distribution spatiale agrégée dans chacun de ces champs et cette tendance n’était pas affectée par le niveau d’infestation. Dans deux champs, la distribution de M. fimbriolata était aléatoire. Une analyse géostatistique a permis l’élaboration des cartes hypsométriques par interpolation par krigage. La dépendance spatiale exprimée en semivario grammes a été utilisée pour cinq champs. Pour les trois autres champs, où la distribution spatiale de M. fimbriolata était agrégée, il n’a pas été possible d’établir des cartes de population en utilisant l’interpolation par krigage, l’écart entre les points de prélèvement étant trop grand pour détecter la dépendance spatiale. Pour les cas où les cartes pouvaient être construites, la distance a varié de 23 à 55 m. En utilisant cette information, nous avons considéré qu’il est nécessaire d’échantillonner six points par hectare pour une estimation plus précise de la population de l’insecte.
DISTRIBUCIÓN ESPECIAL DEL SALIVAZO DE LA CAÑA, MAHANARVA FIMBRIOLATA, EN CAMPOS DE CAÑA DE AZÚCAR

Por

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PALABRAS CLAVE: Saccharum, Caña de Azúcar, Plagas, Muestreos, Salivazo.

Resumen

EL SALIVAZO de la caña de azúcar, Mahanarva fimbriolata (Stal) (Hemiptera: Cercopidae), es una de las plagas más importantes de la caña de azúcar en la región Centro-Sur del Brasil. La información sobre su distribución espacial en los campos de caña de azúcar es importante para el desarrollo de muestreo, con miras a su aplicación en programas de manejo integral. Por tanto, se estudió la distribución espacial de M. fimbriolata en 10 campos de caña cosechada mecánicamente en verde en Catanduva, estado de San Pablo, Brasil. En cada campo de 1.41 hectáreas, se tomaron 150 muestras en una cuadrícula rectangular de 10 × 10.5 m, entre el 27 de diciembre de 2007 y 1 de noviembre 2008. El índice de Morisita de significativamente superior a 1, ocurrió en ocho campos, lo que indicó que en cada uno de esos campos M. fimbriolata tuvo una distribución espacial agrupada y por tanto el patrón no se vio afectado por el nivel de infestación. En dos de esos campos, la presencia de M. fimbriolata fue al azar. El análisis geoestadístico facilitó la construcción de mapas de contorno a través de la interpolación de Kriging en cinco campos, utilizando la dependencia espacial expresada en semivariogramas. Para los otros tres campos en los que M. fimbriolata tuvo una distribución espacial agrupada, no fue posible la construcción de mapas de población mediante la interpolación de Kriging porque la distancia entre los puntos de muestreo era demasiado grande para detectar la dependencia espacial. Para los casos en que los mapas se pudieron construir, las gamas de variación estuvieron entre 23 hasta 55 metros y, con esta información, se estimó que era necesario tomar muestras de 6 puntos/ha para una estimación adecuada de la población de insectos.
FLUCTUATION IN EGG NUMBERS OF THE SUGARCANE STEM BORER
SESAMIA NONAGRIOIDES LEFEBVRE AND EGG PARASITISM
BY PLATYTELENOMUS HYLAS NIXON RELATIVE
TO DIFFERENT STAGES OF CANE GROWTH

By

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KEYWORDS: Sugarcane Stem Borer, Sesamia nonagrioides, Parasitoid, Platytelenomus hylas, Cane Age.

Abstract

SUGARCANE stem borers are the most important pests of sugarcane worldwide and also in Iran. We studied the fluctuation in egg numbers of the stem borer Sesamia nonagrioides Lefebvre and egg parasitism by Platytelenomus hylas Nixon in sugarcane fields of the Karoun Agro-Industry Company (Khuzestan, Iran) in 2005–2006. A ratoon field and plant cane field (both fields were cultivated with variety CP48-103) were selected for sampling. Egg numbers and percentage of parasitised eggs, numbers of sugarcane stalks/hectare and the stalk height were recorded weekly. Results showed that the peak of borer oviposition occurred in mid-August 2005 in the ratoon field, but was in mid-June 2006 in the plant cane field. The percentage of parasitism increased with increasing plant height in ratoon and plant cane fields. Peak percentage of parasitism was 67.8% when the mean of plant height was 96.2 cm in ratoon field in early July 2005 and 78.8% when stalk height was 78 cm in plant cane field (in mid-April 2006).

Introduction

Worldwide, sugarcane is an important tropical and semi-tropical crop (Azizi, 1990). Sugarcane is an important crop in Iran with nearly all 100 000 hectares of sugarcane planted in Khuzestan Province (Anon. 2006). Stem borers are important pests in most of the sugarcane producing areas of the world.

For example, the stem borer Scirpophaga excerptalis Walker infects 16 percent of sugarcane stems in India (Rajendran and Girdharn, 2003). Sesamia nonagrioides Lefebvre and S. cretica Lederer, are the most important pests of this plant in Iran (Ranjbar, 1999).

These pests are multivoltine and their population density varies with each generation (Sayadmansour et al., 2004). They injure the apical meristem producing dead hearts (James, 2004) and eliminate tillers (Askarianzadeh, 2004) of plants. The larval feeding in stalks decreases yields 1.4 percent in refined sugar, 3.92 percent in juice purity and with total losses of 391 kg/ha of white sugar (Sayadmansour et al., 2004).

Seraj (2002) showed that, for each percent internodes infested, there is a decrease of 110 kg white sugar per hectare at Amir Kabir Agro-Ind. Co. Iran (Anon., 2005).

Not surprisingly, varieties differ in their response to stem borer damage. Askarianzadeh et al. (2008a) showed that sugar losses for every 1% bored internodes were 0.17, 0.39 and 0.23%
(equal to 210, 482 and 241 kg sugar) in cultivars of CP70-1143, CP69-1062 and CP48-103, respectively. According to Sayadmansour et al. (2005), the cultivar CP48-103 (with 48.9% and 6.9% bored stalks and internodes, respectively) was the most susceptible, and the cultivar SP71-6163 (with 20.3% and 2.1% bored stalks and internodes, respectively) was the most resistant against stem borer.

The egg parasite, *Platytelenomus hylas* Nixon (Hymenoptera: Scelionidae), has shown promise for biological control of stem borers in Iran. This parasitoid completes its life cycle in 11–14 days and therefore can produce several generations each year. Studies on range of host acceptance showed that only *Sesamia* eggs were attacked by this parasitoid, and it prefers *S. nonagrioides* over *S. cretica* (Abbasipour, 2004).

Different cultivated host and different varieties of cultivated host can influence behavioural characteristics and efficiency of this parasitoid. Research showed that levels of egg parasitism by *P. hylas* on three sugarcane cultivars (CP48-103, CP57-614 and CP69-1062) differed significantly (Askarianzadeh et al., 2008b). Sayadmansour et al. (2008) in olfactometer studies showed that this parasitoid has different responses to corn (cultivar 704) and three sugarcane cultivars (CP48-103, CP69-1062 and CP57-614).

Since parasitism is affected by several factors and much of the variation in parasitism levels is due to direct and indirect influence by the host plant (Faria et al., 2007) and, considering the potential importance of this parasitoid in Iran, fluctuations in oviposition by *S. nonagrioides* and parasitism by the egg parasitoid, *P. hylas*, were studied relative to different stages of cane growth.

**Materials and methods**

An eight hectare ratoon field of the cultivar CP48-103 comprising 264 furrows (200×1.5 m) was selected for our test site. Samplings were conducted from early July until late September 2005. At each sampling time, 30 furrows were selected at random and then 4 stations per each furrow were identified as sample stations. At each station, 0.3 m of row was examined. There were 120 sample stations.

All shoots in each station were removed and examined. The number of egg clutches per station was recorded. Additional information from each station (i.e. number of sugarcane shoots and weekly height measurements) was also recorded.

All egg clutches collected from behind the leaf sheath (the typical oviposition site) were transported to the laboratory. The eggs were then placed in a small Petri dish for 1–2 days. Then, the eggs were inspected for parasitism under a stereo microscope. Also, the height of stalks in each station was measured as described by Sund and Clements (1974).

In September 2005, a plant cane field (21 hectares with 690 furrows) was also selected for survey. The sampling method was the same as for the ratoon field. The sampling program in the plant cane field was continued until late September 2006.

**Results**

**Variation in the number of stem borer eggs in relation to sugarcane weekly growth**

Variations in number of sugarcane stalks per hectare, number of borer eggs and the height of stalks are shown in Figure 1.

Peak number of borer eggs occurred in early September 2005 in ratoon field (333 716 eggs per hectare) when there were about 333 000 stalks per hectare and the height of sugarcane was 208 cm. Therefore, on average, there was nearly one egg per stalk. In the plant field, number of eggs varied more than those in ratoon field (Figure 2).

The peak of the borer eggs occurred early July 2006 (737 865 eggs on 341 112 stalks per hectare). So, there was more than one egg per stalk during September, November and July in plant field.
Variation in percentage of parasitism and sugarcane weekly growth

Variation in percentage of parasitism and weekly growth of sugarcane in the ratoon field is shown in Figure 3. When sugarcane was short (about 21 cm), the level of parasitism was low (near
zero); increasing to 68% parasitism when the height of stalks was 96 cm. In Figure 4, in plant field, the percentage of parasitism was also low when the height of sugarcane was low in September. After that, the parasitism percentage increased gradually until early November when it increased sharply. With regard to the duration of oviposition by the borer in this region, the sharp increase in percentage of parasitism in November could be due to the limited number of borer eggs present in fields, since nearly all eggs are parasitised. After the regrowth of sugarcane in early April 2006, the percentage of parasitism also increased. The peak of parasitism (78.8%) occurred in early May 2006 when the growth rate of sugarcane (plant and ratoon) is increasing.

![Fig. 3—Comparison between weekly growth of cane and percentage of parasitism by P. hylas in raton field.](image1)

![Fig. 4—Comparison between weekly growth of cane and percentage of parasitism by P. hylas in plant field.](image2)
Discussion

Our data show a difference in the number of borer eggs oviposited between ratoon and plant cane fields. In ratoon fields, plants re-generate from stubble and consequently the number of tillers increases rapidly (Kord, 2000). Therefore, 502,000 stalks in ratoon and 302,000 stalks in plant cane field were encountered. According to Figures 1 and 2, when the number of stalks is very high, the oviposition of the pest was low.

Furthermore, when the plants in the ratoon field were starting to re-generate in May, the number of adults of *S. nonagrioides* was low whereas, in plant cane field, the beginning of new plant growth in September corresponded with high numbers of adult moths that were ready for laying eggs on the new plants.

With our knowledge of the biology of sugarcane stem borer (Daniali, 1984) we can estimate the population of adult moths on the first of June from their egg population on the first of May. We can also estimate the size of the adult population in September by monitoring egg numbers on the first of August.

This study showed a positive relationship between sugarcane growth and percentage of parasitism of the stem borer eggs. That is, in ratoon fields, the percentage of parasitism increased with sugarcane growth from early June until the middle of July and then the percentage of parasitism was maintained at a high level. In plant cane fields, since oviposition of the borer was low in November and December, percentage of parasitism was high. This caused difficulty for the parasitoid, as there were limited pest eggs.

In spring, the percentage of parasitism increased with sugarcane growth and peaked in mid-May. Then, with some changes, due to overlap of parasitoid generations, reached a constant level. These results are similar to studies of Oztemis and Kornosor (2007) who reported on the percentage of parasitism by wasp parasitoid *Trichogramma evanescens* on *Ostrinia nubilalis* in corn.

These results are also similar to Abbasipor (2004) who reported on percentage parasitism by *P. hylas* on *S. nonagrioides* in corn fields of Khuzestan Province, Iran. Therefore, because of the high numbers of pest eggs and the low level of parasitism in early September, we plan to release the parasitoid at this time.

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FLUCTUATION DU NOMBRE DES ŒUFS DU FOREUR DE TIGE DE LA CANNE À SUCRE SESAMIA NONAGRIOIDES LEFÉBVRE ET PARASITISME DES ŒUFS PAR PLATYTELENOOMUS HYLAS NIXON EN RELATION AVEC LES STADES DE CROISSANCE DE LA CANNE

Par

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MOTS CLÉS: Foreur de la Tige de Canne à Sucre, Sesamia nonagrioides, Parasitoïde, Platytelenomus hylas, Age de la Canne à Sucre.

Résumé

Les foreurs de tige sont les ravageurs les plus importants de la canne à sucre dans le monde et en Iran. Nous avons étudié la fluctuation du nombre des œufs du foreur de tige Sesamia nonagrioides Lefèbvre ainsi que le parasitisme des œufs par Platytelenomus hylas Nixon dans les champs de canne à sucre de la Karoun Agro-Industry Company (Khuzestan, Iran) en 2005–2006. Un champ en repousse et un en vierge (tous deux cultivés par la variété CP48-103), ont été sélectionnés pour l’échantillonnage. Le nombre des œufs et le pourcentage des œufs parasités, le nombre de tiges/hectare et la longueur de la tige ont été répertoriés chaque semaine. Les résultats ont démontré que le pic d’oviposition se situait mi-août 2005 dans le champ en repousse et mi-juin 2006 dans le champ en canne vierge. Le pourcentage de parasitisme augmentait avec la hauteur de la canne que ce soit en canne vierge ou en repousse. Le pic du parasitisme se situait à 67.8% quand la hauteur moyenne de la canne était de 96.2 cm dans le champ en repousse début juillet 2005 et à 78.8% quand la hauteur des cannes vierges était de 78 cm (mi-avril 2006).
FLUCTUACIÓN EN EL NÚMERO DE HUEVOS DEL BARRENADOR DE LA CAÑA SESAMIA NONAGRIOIDES LEFEBVRE Y EL PARASITISMO DE HUEVOS POR PLATYTELENOMUS HYLAS NIXON EN RELACIÓN CON LOS DIFERENTES ESTADOS DE CRECIMIENTO DE LA CAÑA

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PALABRAS CLAVE: Barrenador de la Caña, Sesamia nonagrioides, Parasitoide, Platytelenomus hylas, Edad de la Caña.

Resumen

Los barrenadores del tallo de caña son las plagas más importantes para el mundo de caña de azúcar así como también para Irán. En el presente trabajo se estudió la fluctuación en el número de huevos del barrenador del tallo Sesamia nonagrioides Lefebvre y el parasitismo de huevos por Platytelenomus hylas Nixon en los campos de caña de azúcar de la Agro-Industria Karoun Company (Khuzestán, Irán) en 2005–2006. Se estudió un campo en soca y uno en plantilla (ambos sembrados con variedad CP 48-103), seleccionados ambos para el muestreo. Semanalmente se registró el número de huevos y el porcentaje de huevos parasitados, así como el número de tallos de caña por hectárea y la altura de los tallos. Los resultados mostraron que el pico de oviposición del barrenador ocurrió en el campo en soca, a mediados de agosto de 2005, en cambio ese pico ocurrió para la plantilla, a mediados de junio de 2006. El porcentaje de parasitismo aumentó con la altura de los tallos tanto en plantilla como en soca. El porcentaje máximo de parasitismo en la soca fue de 67.8%, cuando la altura media de los tallos fue de 96,2 cm a principios de julio de 2005 y de 78.8% en la plantilla, cuando la altura media de los tallos fue de 78 cm (a mediados de abril de 2006).
BIOLOGICAL CONTROL OF THE TERMITE *HETEROTERMES TENUIS* (HAGEN) (ISOPTERA: RHINOTERMITIDAE) BY *BEAUVERIA BASSIANA* (BALS.) VUILL IN CENTRAL MOTZORONGO, VERACRUZ, MÉXICO WITH CARDBOARD TRAPS

By

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KEYWORDS: Termites, Entomopathogenic Fungi, Traps, Control, Pathogenicity.

ABSTRACT

The subterranean termite, *Heterotermes tenuis* (Hagen), has become a major economic pest in sugarcane fields of Mexico, particularly in Veracruz State, due to the damage and losses they cause to the crop. Colonies are difficult to locate due to termite biology and the habitats they infest. In the absence of effective control tactics, we developed the use of the entomopathogen, *Beauveria bassiana*, combined with attractant traps, as an economic and environmentally friendly method of control. This entomopathogen has been shown to be effective on various agricultural pests. The technique is especially attractive because it has no polluting effects on the environment. For these reasons, we chose it as the control agent for traps constructed out of corrugated cardboard. We evaluated two entomopathogenic fungi: strain CP 095, *B. bassiana* and *Metarhizium anisopliae*, METAMOTZ 093, plus two insecticides (fipronil and imidacloprid). Four trials were conducted in sugarcane fields of Central Motzorongo. Field surveys were conducted weekly. Under laboratory conditions the best results were obtained with *B. bassiana* at 7 days causing 100% mortality, whereas with *M. anisopliae* the highest mortality occurred at 9 days. Pathogenicity of *B. bassiana* based on termites found dead in a growth chamber was 90% but 70% effective when combined with *M. anisopliae*, which diminishes its effectiveness.

Introduction

The subterranean termite, *Heterotermes tenuis* (Hagen) (Isoptera: Rhinotermitidae), is one of the most important pests of sugarcane in Brazil, Guatemala and Mexico. According to Novaretti (1985), infestations at planting, at crop maturity and after harvest can cause yield losses up to 10 t/ha per year.

Control of subterranean termites is currently very expensive and not effective due to the difficulty of targeting colonies which are widely dispersed in the soil. Restrictions on the use of highly toxic chemical insecticides have led to research on alternative management strategies for controlling termites. Insecticide applications are now based on levels of pest infestation as determined from surveys and species identification (Macedo *et al.*, 1997).

Monitoring of termite populations has been a major breakthrough in technological developments in the control of subterranean termites, which is being adopted by sugarcane producers. Surveys of population levels and identification of harmful species in sugarcane fields have allowed for more efficient use of termiticides.

The use of toxic attractants in traps for termite control is a promising alternative that has been investigated in several countries (Macedo *et al.*, 1997; Almeida *et al.*, 1998).

The combined use of traps with attractants to enhance contact of the pest with a toxin is now recommended by researchers. In a control strategy for *H. tenuis* with traps of corrugated cardboard
impregnated with an insecticide and entomopathogenic fungi, it is also important to consider the fungicidal effects of the product to be used (Castiglioni et al., 2003).

In addition to their toxic effects, the products used in traps for control of subterranean termites should be slow-acting, non-repellent and transmitted between individuals of the colony.

Thus, when treating a portion of the community, the toxic agent can be distributed throughout the colony when the workers return from feeding. Such slow-acting insecticides can cause the collapse of a colony of termites (Castiglioni and Vendramim, 2003).

The strategy of monitoring and control of termites using traps as attractants (bait), is based on the principle of contact of the microbe or chemical agents with those insects attracted to the bait and transmitting these back to the entire colony (Almeida et al., 1998).

The corrugated cardboard traps are attractive to termites and have been used for monitoring populations of this pest in sugarcane and forest systems. Biological agents such as B. bassiana can also be used in combination with a sublethal dose of an insecticide in the traps (Almeida, 1994).

Such a monitoring technique has been used with forest termites by Iñiguez and Talavera (2006) in the state of Colima, Mexico, with very good results.

Their procedure consisted of burying a 1 litre plastic bucket with holes drilled in the bottom, sides and the lid. A roll of corrugated paper (cellulose source) that serves as food for termites is placed inside.

The goal of this study was to determine the efficiency and pathogenicity of B. bassiana for biological control of subterranean termites in sugarcane, using traps made of corrugated cardboard in Central Motzorongo.

Materials and methods
This study was carried out in 2008 during the maturation phase of sugarcane (August–November). Traps were monitored every seven days during this four month period.

Two insecticides and two entomopathogenic fungi were assessed as shown in Table 1. Four trials were laid in distinct agroclimatic areas. Each treatment was replicated four times.

| Table 1—Active ingredients evaluated in the traps for the control of termites in Central Motzorongo. |
|-------------------------------------------------|---------------------------------|---------------------|
| **Treatments** | **Rate/hectare** | **Concentration** |
| Beauveria bassiana | 1 kg | $2 \times 10^{12}$ |
| Metarhizium anisopliae | 200 g | $2 \times 10^{12}$ |
| B. bassiana and M. anisopliae | 1 kg and 200 g | $2 \times 10^{12}$ |
| Imidacloprid | 30 g | 15% |
| Fipronil | 20 mL | 30% |
| Control | – | – |

Preparation of the traps
The active ingredient was dissolved in 15 litres of water in a 20 litre container. Corrugated cardboard rolls serving as traps were submerged in this solution for one minute for the impregnation of the active ingredient.

Distribution of traps in the field
The distribution of traps impregnated with the active ingredient for control of subterranean termites in sugarcane was set up with 20 traps per hectare according to procedures outlined by Macedo and Macedo (2004) so that the traps were distributed evenly in treated areas.

The traps used as attractants at Central Motzorongo were made of corrugated cardboard with chemical and biological ingredients as shown in Figure 1.
Fig. 1—Diagram of the distribution of traps per site (one hectare) for control of subterranean termites.

Placement of traps in the field

Traps, 7.5 cm diameter × 23 cm high, made of corrugated cardboard were used. These were buried 20 cm deep so that 3 cm was visible above ground for easy location of the traps for assessments.

Results

Samples were taken fortnightly during September and October 2008. At each sampling date, live termites collected were transferred to the laboratory to determine percent of mortality for each of the treatments.

Dead termites were placed in a growth chamber and incubated at 25°C for 10 days to determine the cause of death.

We determined the average daily mortality of termites at 10 days in the laboratory by placing 20 worker termites in a petri dish containing field soil and bait formulation.

Four replicates per treatment were used to calculate the average mortality of individuals killed for each of the treatments evaluated.

Once the percentage daily mortality in treatments with *B. bassiana* and *M. anisopliae* was determined, termites were again placed in a growth chamber in the laboratory at 25°C, to observe if the death was due to the entomopathogenic fungi.

We placed twenty termites per treatment in each of four petri dishes and noted the development of mycelia on the cadavers.

As shown in Figure 2, *B. bassiana* showed a mortality of 100% of the population evaluated seven days after, whereas treatment with *M. anisopliae* alone and in combination with *B. bassiana*, 100% mortality was attained after eight days, while only 60% mortality was observed at the end of the observation period of ten days for the control.

No live termites were found in the traps impregnated with chemical insecticides because the highly toxic ingredients cause immediate death of the workers.
Fig. 2—Mortality of termites in function of observation time in the treatments evaluated.

Mycelium formation and sporulation occurred on 90% of the termites from the *B. bassiana* treatment, and 70% in the treatment in combination with *M. anisopliae*.

This technique is cost effective due to the low-cost of materials that are used such as the corrugated cardboard and the entomopathogenic agents (Table 2).

### Table 2—Cost per hectare for the use of traps as attractants for control of termites in Central Motzorongo.

<table>
<thead>
<tr>
<th>Types of control</th>
<th>Cost of traps per hectare ($)</th>
<th>Cost active ingredient ($)</th>
<th>Cost labour ($)</th>
<th>Total cost per hectare ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traps (with <em>Beauveria bassiana</em>)</td>
<td>60</td>
<td>90</td>
<td>160</td>
<td>320.00</td>
</tr>
<tr>
<td>Traditional (with chemical insecticide)</td>
<td>–</td>
<td>1800</td>
<td>200</td>
<td>2000.00</td>
</tr>
</tbody>
</table>

**Results and discussion**

Using the corrugated cardboard technique, we found that this material is very attractive to termites, as the cellulose contained in this material is easily digestible by termites. Our results confirm the findings of Macedo *et al.* (2004). On average, 2300 termites were found per trap. The traps cause the termites to divert their attention from the sugarcane, and a reduction in damage to the basal internodes of stalks in the field was observed.

Additionally, there is a ripple effect whereby the entomopathogenic agents are spread to the rest of the colony by the contact of infected termites with uninfected ones. The natural dispersal of entomopathogenic fungi is slow and lengthy in contrast to insecticides. This method therefore enhances the rate of spread of the entomopathogen to the colony and degrades quickly.

**Conclusions**

Corrugated cardboard is a very attractive material to termites, as the cellulose contained in this material is more easily digestible. This control option is ecologically safe as the material is biodegradable.

As for the active ingredients used in the traps, better results were obtained with entomopathogenic fungus *B. bassiana*, with a mortality of 100% of the population and one of pathogenicity 90%.
This technique reduces the cost to control this pest as well as serves as an environmentally friendly method of controlling damaging termite infestations.

REFERENCES


LUTTE BIOLOGIQUE CONTRE LE TERMITE HETEROTERMES TENUIS (HAGEN) (ISOPTERA: RHINOTERMITIDAE) PAR BEAUVIERA BASSIANA (BALS.)

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MOTS CLÉS: Termites, Champignon Entomopathogène, Pièges, Lutte, Pathogénicité.

Résumé

Le termite souterrain, Heterotermes tenuis (Hagen), est devenu un ravageur majeur dans les champs de la canne à sucre au Mexique, particulièrement dans l’état de Veracruz, de par les dégâts et pertes causées à la culture. Les colonies sont difficilement localisées par la biologie de l’insecte et le type habitat infesté. En l’absence d’une stratégie de lutte efficace, nous avons préconisé l’utilisation de l’entomopathogène Beauveria bassiana en combinaison avec des pièges attractifs, comme moyen de lutte économique et respectueux de l’environnement. Cet entomopathogène a démontré une efficacité contre plusieurs ravageurs agricoles. La technique est
particulièrement intéressant comme elle n’a aucun effet polluant. Pour cette raison, nous l’avons choisi comme agent de lutte en utilisant des pièges construit avec le carton ondulé. Nous avons évalué deux champignons entomopathogènes : la souche CP 095, *B. bassiana* et *Metarhizium anisopliae*, METAMOTZ 093, en sus de deux insecticides (fipronil et imidacloprid). Quatre essais ont été établis dans des champs de canne à sucre au Motzorongo Central. Les prospections ont été effectuées toutes les semaines. Sous les conditions de laboratoires, les meilleurs résultats ont été obtenus avec *B. bassiana* à 7 jours, occasionnant 100% de mortalité, alors qu’avec *M. anisopliae* la mortalité la plus élevée a été observée après 9 jours. Le pathogénicité du *B. bassiana* en fonction des termites morts dans une chambre de culture était de 90%. L’efficacité était réduite à 70% en combinaison avec le *M. anisopliae*.

CONTROL BIOLÓGICO DE LA TERMITA HETEROTERMES TENUIS (HAGEN) (ISOPTERA: RHINOTERMITIDAE) EMPLEANDO BEAUVERIA BASSIANA (BALS.) VUILL EN TABLEROS TRAMPAS, EN EL CENTRAL AZUCARERO MOTZORONGO, VERACRUZ, MÉXICO

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PALABRAS CLAVE: Termitas, Hongos Entomopatógenos, Trampas, Control, Patogenicidad.

Resumen

LA TERMITA subterránea, *Heterotermes tenuis* (Hagen), se ha convertido en una plaga económica importante en los campos de México, en particular en el Estado de Veracruz, debido a los daños y perjuicios que causan a los cultivos de caña de azúcar. Las colonias son difíciles de localizar debido a la biología de las termitas y de los hábitats que infestan. A falta de tácticas eficaces de control, se ha desarrollado el uso del entomopatógeno, *Beauveria bassiana*, combinada con trampas atrayentes, como un método económico y ambientalmente amigable de control. Este entomopatógeno ha demostrado ser eficaz en diversas plagas agrícolas. La técnica es especialmente atractiva porque no tiene efectos contaminantes sobre el medio ambiente. Por estas razones, hemos elegido como el agente de control de las trampas construidas de cartón corrugado. Se evaluaron dos hongos entomopatógenos: CP cepa 095 de *B. bassiana* y *Metarhizium anisopliae*, METAMOTZ 093, además de dos insecticides (Fipronil e Imidacloprid). Se realizaron cuatro ensayos en los campos de caña de azúcar del Central Motzorongo. Las evaluaciones de campo se llevaron a cabo semanalmente. En condiciones de laboratorio los mejores resultados se obtuvieron con *B. bassiana* a los 7 días, causando una mortalidad del 100%, mientras que con *M. anisopliae* la mortalidad más alta se produjo en 9 días. La patogenicidad de *B. bassiana* sobre la base de las termitas muertas en una cámara de crecimiento fue del 90%, pero el 70% de efectividad cuando se combinó con *M. anisopliae*, debido a disminución a su eficacia.
IDENTIFICATION OF THREE ARMYWORM SPECIES (LEPIDOPTERA: NOCTUIDAE) USING DNA BARCODES AND RESTRICTION ENZYME DIGESTION

By

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KEYWORDS: Mythimna spp., Armyworms, DNA Barcodes, Species Identification.

Abstract

SIX SPECIES of sugarcane armyworms (Mythimna spp.) are known to occur in Mauritius, namely M. pseudoloreyi, M. loreyi, M. insulicola, M. phaea, M. tincta and M. pyrausta. Due to the close resemblance of the adult moths, morphological distinction among the different species is difficult and may lead to misidentification. One new approach for their characterisation involves the use of DNA barcodes to analyse the sequence diversity within a short standardised segment of their genome. Polymorphism in the 5’ end of the mitochondrial cytochrome oxidase I (COI) gene is extensively used as a DNA barcoding system in Lepidopterans. In 2008, adult moths of M. insulicola, M. phaea and M. pseudoloreyi were reared from field-collected larvae. Two nucleic acid extraction methods were evaluated, both yielding high quality DNA for molecular studies. DNA extractions were performed from different body parts including abdomen, leg and wing. A ~700 bp PCR fragment amplified from the three species, using primers HCO2198/LCO1490, was digested using restriction enzymes. A combination of four enzymes RsaI, TaqI, PvuII and SacI successfully allowed distinction of the three species of armyworms tested. The PCR products from the three species were cloned and sequenced. A 658 bp fragment from each of M. insulicola, M. phaea and M. pseudoloreyi was submitted to Genbank and respectively recorded as Leucania insulicola, GQ353294; Leucania phaea, GQ353295; and Leucania loreyi, GQ353296. Using the Barcode of Life identification engine (BOLD-ID), high sequence identities were obtained with Leucania species (Noctuidae: Hadeninae)– 99.54% for L. phaea and Leucania sp. (from Kenya), 100% for L. loreyi and Leucania sp. and 99.85% for L. insulicola and L. striata (from Madagascar). The L. phaea sequence diverged by 7.3% and 10.6% from those of L. loreyi and L. insulicola respectively. A sequence divergence value of 8.5% was observed between L. loreyi and L. insulicola. DNA barcoding and sequencing could provide useful information for classification and characterisation of armyworms.

Introduction

In Mauritius, infestations of sugarcane fields by armyworms belonging to the genus Mythimna, (Lepidoptera: Noctuidae) were initially reported in 1959 (MSIRI, 1960). In subsequent years, these pests did not pose a major threat to sugarcane and were under control.

With the introduction of mechanised sugarcane harvesting and the adoption of trash blanketing practices, severe outbreaks were observed after 1992. Attacks by armyworms cause retardation in shoot development and this is more pronounced when associated with other stress factors including drought conditions.

During severe outbreaks, total defoliation of affected fields may occur. To-date six species of sugarcane armyworms are known to occur in Mauritius, namely M. pseudoloreyi, M. loreyi, M. insulicola, M. phaea, M. tincta, and M. pyrausta (Ganeshan, 2007).
Control of armyworms is achieved through the use of insecticides. Chemical control can have negative impacts on the cane ecosystem in Mauritius, where a biological control strategy has always been adopted for the management of sugarcane pests. Six species of parasitoids have been identified from *Mythimna* spp. in Mauritius (Ganeshan, 2001) and the entomopathogen *Metarhizium anisopliae*, has also been observed on larvae and pupae (Beehary-Panray and Rajabalee, 1998). However, the application of biological control agents is reliant on accurate identification of the pest species involved and for *Mythimna* spp. this has been a major difficulty. Morphological distinction is problematic due to the close resemblance of the adult moths and this may lead to misidentification of species.

Molecular biology tools, particularly the use of ‘DNA barcodes’, can complement traditional morphologically based taxonomy to determine the identity of insect pest species (Hebert et al., 2003). This method relies on the sequence diversity in the *cytochrome-c oxidase* I (COI) gene of the mitochondrial DNA. Application of DNA barcodes in taxonomy is gaining momentum and there are currently various efforts worldwide in this area namely: Consortium for the Barcode of Life, All Lepidoptera Barcode of Life Initiative, Fish Barcode of Life Initiative, Canadian Centre for DNA Barcoding, Canadian Barcode of Life Network and All Birds Barcode of Life Initiative. These form part of the International Barcode of Life Initiative, which aims to have a global barcode system for all the species present on earth (Savolainen et al., 2005). The Barcode of Life Data Systems (BOLD) has thus been set-up (http://www.barcodinglife.org) and can be considered as an online barcoding information system for collection, management and analysis of DNA barcodes.

For Lepidoptera, which constitute the second most diverse insect order, with more than 180 000 known species and many more unknown ones, DNA barcodes are expected to identify more than 95% of species. In Costa Rica, in a study comprising of 4260 specimens of which 521 were *Lepidoptera* species, Hajibabaei et al. (2006) unambiguously identified 97.9% of the test species. Using DNA barcodes, it was shown that the sequence of *Diatraea saccharalis* shared 99% homologies with members of the Crambidae family (Bravo et al., 2008). Previously, there was confusion regarding classification of these moth borers in either the Pyralidae or Crambidae families. Similarly, it is expected that barcodes will provide more insight into the classification of the six *Mythimna* spp. in Mauritius. The genus *Leucania* has been reviewed and several species belonging to this genus were assigned to the *Mythimna* genus (Holloway et al., 1987). However, there is still some confusion on the taxonomic nomenclature of this genus, which needs revision.

The main objective of this project is to investigate the usefulness of DNA barcodes for distinguishing the six *Mythimna* spp. present in Mauritius.

**Material and methods**

**Armyworm collection**

Larvae were collected from sugarcane fields in 2008 and were reared to adult in the laboratory. Adult moths were identified using morphological characters (Ganeshan, 2007). The adult specimens were preserved in 90% ethanol until processed. Only three species were encountered: *M. pseudoloreyi*, *M. insulicola* and *M. phaea*. DNA was extracted from the three species (Table 1).

**DNA extraction**

An appropriate DNA extraction technique is a critical step for successful application of a DNA barcoding system for insects. It is important to have good quality DNA for amplification of the mitochondrial DNA fragment by the polymerase chain reaction (PCR). Two DNA extraction protocols were evaluated. Before homogenising, the specimens were removed from the alcohol and allowed to dry.

In the first method, the protocol described by Zhou et al. (2000) was followed for extraction of DNA from single moths. After removing the wings and legs, the moth was homogenised using a sterilised mortar and pestle (with 1 mL of extraction buffer – 10 mM Tris HCl (pH 7.5), 60 mM NaCl and 10 mM EDTA). 600 μL of the homogenate were transferred to a 2 mL microcentrifuge tube and an
equal volume of post-grinding buffer (200 mM Tris HCl pH 9.0, 30 mM EDTA and 2% SDS) were added. 140 μg of proteinase K was added and the tubes were incubated in a water bath at 50°C overnight. Sodium acetate (pH 4.8) was added to a final concentration of 0.3 M. The contents of the tubes were transferred to a 15 mL falcon tube and an equal volume of phenol was added and centrifuged at 8000 rpm. The aqueous phase was recovered and extracted with an equal volume of chloroform: isoamyl alcohol (24:1). To the supernatant, two volumes of 95% ethanol were added and DNA precipitated at –20°C for 2 h. The DNA was recovered by centrifugation and after air-drying, was resuspended in 100 μL of sterile distilled water.

In the second method, a modified CTAB method was adopted. Adult moths devoid of wings and legs were homogenised in 1 mL CTAB buffer (2% CTAB, 1.4 M NaCl, 20 mM EDTA pH 8.0, 100 mM Tris-HCl pH 8.0, 0.1% mercaptoethanol and 200 μg proteinase K) using a mortar and pestle. 1 mL of the homogenate was transferred to a centrifuge tube and incubated for 45 min at 60°C. An equal volume of phenol: chloroform: isoamyl alcohol (25:24:1) was added and centrifuged for 10 min at 14 000 rpm. A second extraction step was performed on the supernatant using an equal volume of chloroform: isoamyl alcohol (24:1). DNA was precipitated with 1/10 volume of sodium acetate (3.0 M) and an equal volume of 95% ethanol (–20°C for 2 h). The DNA was pelleted by centrifugation and following air-drying, was resuspended in 500 μL of sterile distilled water.

Improvements to the two methods included an optional RNA digestion step. This was performed after the chloroform:isoamyl alcohol step; the supernatant was treated with 100 μg of RNase A and incubated at 37°C for 3 h. Attempts were also made to extract DNA from detached wings and legs of specimens (Table 1).

Table 1—Different extraction methods performed.

<table>
<thead>
<tr>
<th>Specimen number</th>
<th>Sample number</th>
<th>Mythimna species</th>
<th>Extraction method followed</th>
<th>Insect part used</th>
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* optional RNase digestion performed

Amplification of DNA barcodes

Primer pair LCO1490/HCO2198 (Folmer et al., 1994) amplifies a ~700 bp fragment of the mitochondrial COI gene. PCR was performed in a total volume of 50 μL with 0.2 mM dNTPs, 1X PCR buffer, 0.3 μM of forward primer (LCO1490, 5’-GGTCAACAAATCTAATAAGATATTGG and reverse primer HCO2198 (5’-TAAACTTCAGGGTGACCAAAAAATCA) and 1 U of Taq polymerase (Roche diagnostics, USA) and 1.5 μL of template DNA. The mixtures were set in a thermal cycler using the following thermal profile: denaturation at 94°C for 10 min followed by 35 cycles of 94°C for 30 s,
50°C for 30 s and 72°C for 1 min, and a final elongation step at 72°C for 10 min. Amplified fragments were separated by 1% agarose gel electrophoresis and visualised under UV light.

**Restriction fragment length polymorphism (RFLP)**

The ~700 bp PCR fragments amplified using HCO1490/HCO2198 were digested with enzymes *RsaI*, *PvuII*, *TaqI* and *SacI* as per manufacturer’s instructions (Roche Diagnostics). Digestion products were separated by 1% agarose gel electrophoresis and visualised under UV light.

**Cloning and sequencing**

One ~700 bp fragment amplified from each of the three species (*M. pseudoloreyi, M. insulicola* and *M. phaea*) was purified from agarose gel using the QIAquick Gel Extraction Kit (Qiagen) and cloned using the pGEM T Easy Vector system (Promega). Subsequently, the inserts were sequenced using an ABI 310 Genetic Analyser using the Big dye 3.1 Sequencing Kit (Applied Biosystems, USA) using universal primers.

**Sequence analysis**

COI DNA sequences from *M. pseudoloreyi, M. insulicola* and *M. phaea* were compared with other sequences from Genbank. The sequences were also used for species identification using the BOLD-IDS (barcode identification engine http://www.barcodinglife.org/). In order to establish the phylogenetic relationship of the three *Mythimna* spp., the primer sequences were trimmed and sequences were aligned with other sequences retrieved from BOLD and Genbank (Table 2) using Clustal X. Mega3 was used to construct a neighbour-joining phylogenetic tree based on Kimura 2 parameter (K2P) genetic distances and 1000 replicated bootstrap values.

<table>
<thead>
<tr>
<th>Table 2—Sequences included in phylogenetic analysis of <em>Mythimna</em> sp.</th>
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<tbody>
<tr>
<td><strong>Species</strong></td>
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</tr>
<tr>
<td><em>M. phaea</em> (Leucania phaea)</td>
</tr>
<tr>
<td><em>M. pseudoloreyi</em> (Leucania loreyi)</td>
</tr>
<tr>
<td>Noctua atlantica</td>
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<td>Schinia pulchripennis</td>
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<td>Leucania striata*</td>
</tr>
<tr>
<td>Leucania sp*</td>
</tr>
<tr>
<td>Leucania stenographa*</td>
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</tbody>
</table>

* Sequences obtained from Barcode of Life database; 1 Name as accepted by Genbank (this study)
2 Non-Public sequences in BOLD (Permission sought from authors)
Results and discussion

Amplification of DNA barcodes

The ~700 bp fragment was successfully amplified with all 20 DNA extracts, AR001-AR020 (Figure 1).

Extracts obtained using the Zhou et al. (2000) method (AR001-004 and AR013-016) as well as the remaining ones (CTAB method) were suitable for the generation of DNA barcodes from *Mythimna* spp.

The optional RNase step was performed for only three extracts (AR011, AR017 and AR018 in Lanes 11, 17 and 19 respectively) and there was not much difference in product amplification.

![Fig. 1](image)

Fig. 1—Amplification of the ~700 bp mitochondrial COI DNA fragment from extracts AR001-AR020 (Lanes 1–20), Lanes 21–22 are water controls and M is 100 bp marker XIV (Roche).

Restriction fragment length polymorphism (RFLP)

The ~700 bp products amplified with primers HCO1490/LCO2198 were digested using restriction enzymes *Rsa*I, *Taq*I, *Sac*I and *Pvu*II (Figure 2). A combination of restriction patterns with at least two enzymes allowed discrimination between the three *Mythimna* spp. tested. *Rsa*I and *Taq*I could differentiate *M. pseudoloreyi* and *M. insulicola* from *M. phaea*.

The *Sac*I recognition site, which is only present in the *M. pseudoloreyi* fragment, was used to separate *M. pseudoloreyi* from *M. insulicola*. Enzyme *Pvu*II also confirmed the slight difference existing between *M. pseudoloreyi* and *M. insulicola* (Figure 2), but the digested product was very close to 700 bp.

The PCR-RFLP described above is a simple technique for differentiating the three armyworm species *M. pseudoloreyi, M. insulicola* and *M. phaea*. In 2009, additional specimens including *M. loreyi, M. tincta,* and *M. pyrausta* will be collected and the method further validated.

Sequence analysis

Sequences obtained from cloned HCO1490/LCO2198 PCR products of *M. insulicola, M. phaea* and *M. pseudoloreyi* were edited to remove the primer region and deposited in Genbank. The curators have accepted the entries as *Leucania insulicola, L. phaea* and *L. loreyi* respectively (GQ353294-6). These names will be used for further discussion in the current paper in order to avoid confusion. It is expected that, with further analysis of barcode data from the three other *Mythimna* species in Mauritius (*M. loreyi, M. tincta* and *M. pyrausta*), the issue of classification will be clearer.
Analysis in the Barcode of Life Identification Engine (BOLD-ID) was performed using the full barcodes and very high (99%) homologies were obtained with specimens belonging to the *Leucania* genus (Noctuidae; Hadeninae) (Table 3). However, these sequences are not currently publicly available and requests were made to the authors for access. Interestingly, the closest matches were either regional specimens, e.g. *L. striata* (LTOL390-09) was collected in Madagascar while the unclassified *Leucania* sp. (PMANL304-09) was collected in Kenya, or pests of sugarcane: specimen *L. stenographa* (ANICB181-06) originates from Australia where this species (=*L. loreyi*imima) is known to infest sugarcane plantations (Edwards, 1992).

Table 3—Sequence similarities of *Leucania (Mythimna)* from this study with those from related species.

<table>
<thead>
<tr>
<th>Species</th>
<th>Homologies</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>L. insulicola</em></td>
<td>99.85 % with <em>Leucania striata</em> (LTOL390-09) - from Madagascar</td>
</tr>
<tr>
<td><em>L. phaea</em></td>
<td>99.54% with unidentified <em>Leucania</em> sp. (PMANL304-09) - from Kenya</td>
</tr>
<tr>
<td><em>L. loreyi</em></td>
<td>100 % with unidentified <em>Leucania</em> sp. (PMAN310-09) - 98.1 % with <em>Leucania stenographa</em> (ANICB181-06) - from Australia</td>
</tr>
</tbody>
</table>

The sequences from this study were compared with those from other *Mythimma* and *Leucania* species publicly available from BOLD. The COI sequence of *L. insulicola* (GQ353294) diverged by 10.6% from *L. phaea* while there is a divergence of 7.3% from *L. loreyi*. For *L. 
insulicola and *L. loreyi*, there is a sequence divergence of 8.5% (Table 4). With such high divergence at nucleotide level, it is very easy to distinguish between the three species being studied. The average overall mean divergence for the 15 species considered in Table 4 is 8.5% (±0.7% SE). It should be noted that only *Mythimna* and *Leucania* sp. have been included in Table 4.

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Using sequences of the mitochondrial COI gene of moths, Hebert *et al.* (2003) showed that there is an average sequence divergence of 0.25% for conspecific individuals while for congeneric species, an average of 6.5% was observed. For the sugarcane stem borer, *Busseola* sp., interspecific divergence of > 4.5% has been reported (Assefa *et al*., 2007). However, caution should be made using COI sequence divergence information for species delimitation (Whinnett *et al*., 2005). It is also important to consider morphological characteristics for taxonomy purposes.

A phylogenetic tree was constructed using the three *Leucania* (*Mythimna*) spp. from this study and selected related sequences from Genbank and BOLD (Figure 3). These species clustered within the *Mythimna/Leucania* group.

**Conclusions**

A simple and quick method for distinguishing among *L. insulicola*, *L. phaea* and *L. pseudoloreyi*, based on PCR-RFLP of part of the mitochondrial COI gene is described in this study.

At nucleotide level, the three species shared high homologies with moths of *Leucania* spp., which occur either in neighbouring countries e.g Madagascar or as pests of sugarcane in Australia.

These sequences have currently been deposited in Genbank as *L. insulicola*, *L. phaea* and *L. loreyi*. The high percentage divergence among the three sequences indicates the occurrence of three
distinct species. Divergence of 7.3% and 10.6% was observed between *L. phaea* sequence and those of *L. pseudoloreyi* and *M. insulicola* respectively. The latter two species had 8.5% sequence divergence. DNA barcoding is effective and very convenient for distinguishing closely related and morphologically similar species.

*Fig. 3—Neighbour-Joining phylogenetic tree based on Kimura-2 parameter genetic distances. *Plutella xylostella* is an out group. Only bootstrap values (1000 replicates) greater than 50% are shown.*

**Acknowledgements**

The authors wish to thank the following persons from Barcode of Life Data Systems (BOLD) for providing non-public barcode sequence data: Dr Scott Miller (Smithsonian Institution,
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REFERENCES


L’UTILISATION DE BARCODES ADN ET DES ENZYMES DE RESTRICTION POUR IDENTIFIER TROIS ESPÈCES DE CHENILLES LÉGIONNAIRES (LÉPIDOPTERA: NOCTUIDAE)

Par

N. JOOMUN, S. GANESHAN et A. DOOKUN-SAUHTALLY

Mauritius Sugar Industry Research Institute, Réduit, Maurice

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Résumé

SIX ESPÈCES de chenilles légionnaires de la canne à sucre (Mythimna spp.) sont connues à Maurice, notamment M. pseudoloreyi, M. loreyi, M. insulicola, M. phaea, M. tincta et M. pyrausta. En raison de la ressemblance morphologique des adultes et de la difficulté de distinguer les papillons, des erreurs d'identification sont existantes. Une nouvelle approche implique l'utilisation des barcodes moléculaires. Le polymorphisme, sur une courte séquence d’un fragment d’ADN conservé du gène mitochondrial codant pour la première sous-unité de la cytochrome oxydase (COI), est couramment utilisé comme barcodes pour identifier des Lépidoptères. En 2008, les larves collectées aux champs provenant de trois espèces M. insulicola, M. phaea et M. pseudoloreyi ont été élevées en laboratoire. Deux méthodes d'extraction d’ADN ont été testées sur les pattes, les ailes et l’abdomen des adultes. Les deux méthodes ont donné des résultats satisfaisants. Des fragments de ~ 700 pb, amplifiés des trois espèces par la technique PCR avec les amorces HCO2198/LCO1490, ont été coupés à l'aide des enzymes de restriction. La distinction des trois espèces de chenilles légionnaires a été possible avec une combinaison de quatre enzymes notamment Rsal, TaqI, PvuII et SacI. Les produits PCR amplifiés de M. insulicola, M. phaea et M. pseudoloreyi ont été clonés et séquencés et un fragment de 658 pb pour chaque espèce a été enregistré dans Genbank comme suit: Leucania insulicola (numéro d’accession GQ353294), L. phaea (GQ353295) et L. loreyi (Q353296). L'analyse de ces barcodes avec le moteur de recherche de BOLD-ID (base de données ‘Barcode of Life Datasets’) indique une forte identité de séquence avec les membres du genre Leucania (Noctuidae: Hadeninae): 99.54% entre L. phaea et Leucania spp. (de Kenya), 100% entre L. loreyi et Leucania spp. et 99.85% entre L. insulicola et L. striata (de Madagascar). L. phaea présentait un pourcentage de variation de 7.3% et de 10.6% par rapport à L. loreyi et L. insulicola respectivement. D’autre part, une divergence de 8.5% au niveau de la séquence a été observée entre L. loreyi et L. insulicola. Les informations obtenues avec les barcodes ADN seront très utiles pour déterminer les espèces de chenilles légionnaires.
IDENTIFICACIÓN DE TRES ESPECIES DE GUSANOS COGOLLEROS (LEPIDOPTERA: NOCTUIDAE) USANDO CÓDIGOS DE ADN Y DIGESTIÓN POR ENZIMO DE RESTRICCIÓN

Por

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PALABRAS CLAVE: Mythimna spp., Gusano Cogollero, Códigos de Barras del ADN, Identificación de Especies.

Resumen
Seis especies de gusanos cogolleros de la caña de azúcar (Mythimna spp.) existen en Mauricio, en específico, M. pseudoloreyi, M. loreyi, M. insulicola, M. phaea, M. tincta y M. pyrausta. Debido al gran parecido de las mariposas adultas, la identificación morfológica entre las distintas especies se dificulta. Un nuevo enfoque para su caracterización involucra el uso de códigos de barra del ADN para analizar la diversidad de secuencia dentro de un pequeño segmento estándar de su genómico. El polimorfismo en el extremo 5′ del gen mitocondrial citocromo oxidasa I (COI, por sus siglas en Inglés) es usado ampliamente como un sistema de código de barras de ADN en los Lepidópteros. En 2008, mariposas adultas de M. insulicola, M. phaea y M. pseudoloreyi fueron criadas a partir de larvas colectadas en el campo. Dos métodos de extracción de ácidos nucléicos se evaluaron, ambos rendiendo ADN de alta calidad para estudios moleculares. Extracciones de ADN se efectuaron a partir de distintas porciones corpóreas, que incluyeron abdomen, pata y ala. Un fragmento de ~700 pares de bases (pb) de cada una de las tres especies se amplificó por medio de la reacción en cadena de la polimerasa (PCR, por sus siglas en Inglés) usando los iniciadores (primers) HCO2198/LCO1490, luego de lo cual se digirió usando enzimos de restricción. Una combinación de cuatro enzimos Rsa1, TaqI, PvuII y SacI permitió distinguir exitosamente a las tres especies de gusanos cogolleros evaluados. Los productos de PCR de las tres especies fueron clonados y secuenciados. Un fragmento de 658 pb de cada una de las especies M. insulicola, M. phaea y M. pseudoloreyi fueron enviadas a la base de datos ‘Genbank’ y registrados, respectivamente, como Leucania insulicola, GQ353294; Leucania phaea, GQ353295; y Leucania loreyi, GQ353296. Usando el mecanismo de identificación de Código de Barras de la Vida (en Inglés, Barcode of Life identification engine, BOLD-ID), se identificaron (con gran probabilidad) secuencias con las especies de Leucania (Noctuidae: Hadeninae)- 99.5% para L. phaea y Leucania sp. (de Kenia), 100% para L. loreyi y Leucania sp., y 99.8% para L. insulicola y L. striata (de Madagascar). La secuencia de L. phaea fue diferente en un 7.3% y 10.6% de aquellas de L. loreyi y L. insulicola, respectivamente. Un valor de divergencia de 8.5% se observó entre L. loreyi y L. insulicola. La secuencia de L. phaea fue divergente en un 7.3% y 10.6% de aquellas de L. loreyi y L. insulicola, respectivamente. El código de barras de ADN y la secuenciación pueden proveer de información útil para la clasificación y caracterización de gusanos cogolleros.
OCCURRENCE OF THREE GENOTYPES OF SUGARCANE YELLOW LEAF VIRUS IN A VARIETY COLLECTION IN MAURITIUS

By

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KEYWORDS: Sugarcane, SCYLV, Virus Genotypes, Virus Diversity.

Abstract

SUGARCANE yellow leaf virus (SCYLV) is widely distributed in Mauritius, but so far the characterisation of genotypes of the virus has not been determined. RT-PCR primers were used to identify genetic diversity of the virus in a variety collection plot. Total nucleic acids were extracted from leaves of thirteen introduced varieties infected by SCYLV and a two-step RT-PCR was optimised for each of the three genotype-specific primer pairs CUB-F/CUB-R, REU-F/B-REU, and PER-F/PER-R tested. The presence of three SCYLV genotypes namely the BRA-PER, CUB and REU was confirmed in the germplasm collection. Genotype REU was observed in 10 varieties while 4 varieties were infected by genotype BRA-PER. Mixed infection with genotypes CUB and REU was observed in variety Co6304 while Q88 was co-infected by genotypes BRA-PER and REU. PCR fragments of 363 bp (BRA-PER), 452 bp (CUB) and 905 bp (REU) amplified from varieties PR67245, Co6304 and S17 were cloned and sequenced. Blast analysis of these three sequences showed high homologies with the corresponding genotype sequences from GenBank – 100% similarity with isolate Taiwl (AJ491144, BRA genotype), and > 99% similarity with isolates CUB-YL1 (AM083988) and REU-YL2 (AM072756) respectively. Recent screening of some local commercial cultivars revealed infection by REU and BRA-PER genotypes. Further intensive surveys are being carried out to assess the distribution of the three SCYLV genotypes in sugarcane fields in Mauritius.

Introduction

Yellow leaf disease of sugarcane (previously called yellow leaf syndrome) occurs in all major sugarcane producing countries of the world (Lockhart and Cronjé, 2000). The causal agent, Sugarcane yellow leaf virus (SCYLV), belongs to the genus Polerovirus of the family Luteoviridae (D’Arcy and Dormier, 2005).

SCYLV is transmitted mainly by infected cane setts and aphid vectors, Melanaphis sacchari and Rhopalosiphum maidis.

The disease is characterised by an intense yellowing of the midrib on the abaxial surface of the leaf, extending to the whole leaf as the disease progresses. Necrosis of leaves, accumulation of sucrose in leaves and shortening of terminal internodes resulting in a fan-like appearance can also be observed in diseased plants.

These symptoms, nevertheless, can also be associated with other biotic and abiotic factors including water stress. Plants may also be infected without exhibiting outward symptoms.

Leaf yellows disease caused by sugarcane yellows phytoplasma is also responsible for similar symptoms in sugarcane in some countries, including Mauritius (Cronjé et al., 1998; Aljanabi et al., 2001; Arocha et al., 2005).
SCYLV infection has been reported to result in yield losses. In Brazil up to 20% yield loss has been observed in cultivar SP71-6163 (Vega et al., 1997). Yield losses may occur even in the absence of visible symptoms (Rassaby et al., 2003; Grisham et al., 2009).

Various studies have shown that SCYLV is quite a variable virus (Abu-Ahmad et al., 2006a,b; Moonan and Mirkov, 2002). Phylogenetic studies by Abu-Ahmad et al. (2006b) identified four genotypes of SCYLV of different geographical origins (genotypes BRA from Brazil, PER from Peru, CUB from Cuba and REU from Réunion). Specific reverse-transcription PCR was developed for these genotypes, but due to the close similarity between BRA and PER genotypes, they were aggregated into a single group termed BRA-PER. Variations in infection capacity and virulence have also been reported among the different genotypes (Abu-Ahmad et al., 2007a,b).

The presence of SCYLV in Mauritius was confirmed in 1996 (Saumtally and Moutia, 1997). Recent studies on the prevalence of the virus in commercial sugarcane cultivation showed infection rates of more than 50% in certain varieties (MSIRI, 2008). However, there has not been any extensive study regarding the occurrence of genotypes present in Mauritius. From only a few samples screened by Abu-Ahmad et al. (2006b), REU and BRA-PER genotypes were observed in Mauritian cultivars. However, the diversity of SCYLV in Mauritius may be much higher since SCYLV isolate MUS1 from Mauritius (variety M 99/48) could not cluster with genotypes BRA, PER and REU (Abu-Ahmad et al., 2006a).

The current study was initiated to verify the occurrence of genotypes of SCYLV in a variety collection plot.

Material and methods

Total nucleic acid extractions

Leaf samples were collected from 13 introduced varieties in a collection at Réduit (Table 1) and total nucleic acids were extracted using the CTAB protocol. 1.0 g of leaf tissue was ground in liquid nitrogen and transferred to 15 mL tube with 5 mL CTAB buffer (2% CTAB, 1.4 M NaCl, 20 mM EDTA pH 8.0, 100 mM Tris-HCl pH 8.0, 0.2% w/v β-mercaptoethanol). After incubation at 60°C for 1 h, an equal volume of chloroform:isoamylalcohol (24:1) solution was added and centrifuged at 9000 rpm for 10 min. The extraction step was repeated once more and the nucleic acids were precipitated using two-third volume of isopropanol. Following two washes in 70% ethanol, the pellets were recovered, allowed to dry and resuspended in 500 μL of sterile distilled water.

<table>
<thead>
<tr>
<th>Variety</th>
<th>Imported from</th>
<th>Year of introduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 BJ 6732</td>
<td>Barbados</td>
<td>1983</td>
</tr>
<tr>
<td>2 B 69337</td>
<td>Barbados</td>
<td>1982</td>
</tr>
<tr>
<td>3 CP 722086</td>
<td>USA</td>
<td>1983</td>
</tr>
<tr>
<td>4 Co 6304</td>
<td>India</td>
<td>2003</td>
</tr>
<tr>
<td>5 PR 67245</td>
<td>Puerto Rico</td>
<td>1983</td>
</tr>
<tr>
<td>6 N 13</td>
<td>South Africa</td>
<td>1982</td>
</tr>
<tr>
<td>7 J 593</td>
<td>South Africa</td>
<td>1982</td>
</tr>
<tr>
<td>8 H 746418</td>
<td>Hawaii</td>
<td>1983</td>
</tr>
<tr>
<td>9 Q 88</td>
<td>Australia</td>
<td>1969</td>
</tr>
<tr>
<td>10 R 534040</td>
<td>Fiji</td>
<td>1972</td>
</tr>
<tr>
<td>11 SP 701423</td>
<td>Brazil</td>
<td>1982</td>
</tr>
<tr>
<td>12 VMC 67611</td>
<td>Philippines</td>
<td>1982</td>
</tr>
<tr>
<td>13 S 17</td>
<td>US World collection</td>
<td>1962</td>
</tr>
</tbody>
</table>
Reverse transcription PCR

(i) Primers YLS 462/111
The presence of SCYLV in the samples was confirmed first using RT-PCR with SCYLV specific primers YLS 462/111 (Irey, unpublished)

(ii) Genotype specific primers (BRA-PER, CUB and REU)
RT-PCR for each of the BRA-PER, CUB and REU genotypes was optimised separately. Sequences of primers used (Abu-Ahmad et al., 2006b) are detailed in Table 2.

Table 2—Primers for specific amplification of SCYLV genotypes BRA-PER, CUB and REU.

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Primer</th>
<th>Sequence (5’-3’)</th>
<th>Expected Product size (bp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRA-PER</td>
<td>PER-F</td>
<td>AAC TGC TGC GTC AGG CCC A</td>
<td>362</td>
</tr>
<tr>
<td></td>
<td>PER-R</td>
<td>GAC GAG CTT GCG TTG TTT TTC T</td>
<td></td>
</tr>
<tr>
<td>CUB</td>
<td>CUB-F</td>
<td>GTG CTT CTC CCG GCG GTT CAC T</td>
<td>450</td>
</tr>
<tr>
<td></td>
<td>CUB-R</td>
<td>ATT CGA GAA CAA CCT CCG CCT C</td>
<td></td>
</tr>
<tr>
<td>REU</td>
<td>REU-F</td>
<td>CAA GCT TCT AGC GGG AAT C</td>
<td>905</td>
</tr>
<tr>
<td></td>
<td>B-REV</td>
<td>CAG TTG CTC AAT GCT CCA CG</td>
<td></td>
</tr>
</tbody>
</table>

1.5 µL of total nucleic acids was mixed with 1.0 µL of reverse primer (10 mM) RT-PCR and made to 10 µL using sterile distilled water. Denaturation was performed at 95°C for 1 min followed by immediate quenching on ice for at least 2 min.

The reverse transcription mix (10 µL) was then added. It comprised 4 µL of 5X RT buffer (Roche), 1.0 µL of dNTPs (10 mM each), 0.5 µl of RNase Inhibitor (20 U/µL), 1.0 µL of 40 U/µL M-MuLV RT (Roche) and sterile distilled water to 10 µL. The RT reaction mix was incubated at 42°C for 1 h and then denatured at 95°C for an additional 3 min.

1 µL of cDNA was used as template for PCR including 1X PCR buffer (including Mg), 200 nM of each of forward and reverse primers, 0.2 mM of each nucleotide, 1 U of Taq polymerase (Roche) and sterile distilled water to a final volume of 50 µL.

The amplification consisted of a denaturation phase of 95°C for 3 min, followed by 35 cycles (94°C for 30 s, 57°C for 1 min- genotype REU (or 61°C for genotypes CUB and BRA-PER), and 72°C for 1 min and 15 s), followed by a final cycle at 72°C for 10 min in a thermal cycler (Veriti, Applied Biosystems). PCR products were separated by electrophoresis in a 1% agarose gel, stained using ethidium bromide and visualised under UV light.

Cloning and sequencing
The pGEM T Easy Vector system (Promega) was used to clone three PCR products (corresponding to each genotype- REU from S17, CUB from Co6304 and BRA-PER from PR67245) according to manufacturers’ recommendations. Following plasmid extraction with the QIAprep Spin Miniprep kit (Qiagen), sequencing was performed using an ABI 310 Genetic Analyser.

Analysis of cloned sequences was performed using Bioedit software and alignment with ClustalW. All sequences from this study were deposited in the Genbank database. Additionally, sequences of SCYLV genotypes were retrieved from Genbank (Table 3) and used for phylogenetic analysis.
Table 3—Isolates of SCYLV used for comparison.

<table>
<thead>
<tr>
<th>Isolate</th>
<th>Variety</th>
<th>Origin</th>
<th>Genbank Accession nos</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRA-PERmu</td>
<td>PR67245</td>
<td>Mauritius</td>
<td>G0907000*</td>
</tr>
<tr>
<td>CUBmu</td>
<td>Co6304</td>
<td>Mauritius</td>
<td>G0907001*</td>
</tr>
<tr>
<td>REUmu</td>
<td>S17</td>
<td>Mauritius</td>
<td>G0907002*</td>
</tr>
<tr>
<td>CUB-YL1</td>
<td>C132-81</td>
<td>Cuba</td>
<td>AM083988</td>
</tr>
<tr>
<td>REU-YL3</td>
<td>SP71-6163</td>
<td>Réunion</td>
<td>AM085306, AM085307</td>
</tr>
<tr>
<td>REU-YL2</td>
<td>R490</td>
<td>Réunion</td>
<td>AM072756</td>
</tr>
<tr>
<td>REU-YL1a</td>
<td>R570</td>
<td>Réunion</td>
<td>AM072754</td>
</tr>
<tr>
<td>REU-YL1b</td>
<td>R570</td>
<td>Réunion</td>
<td>AM072755</td>
</tr>
<tr>
<td>REU42</td>
<td>SP71-6163</td>
<td>Réunion</td>
<td>AJ621159</td>
</tr>
<tr>
<td>SCYLV-F</td>
<td>CP65-357</td>
<td>Florida</td>
<td>AJ249447</td>
</tr>
<tr>
<td>MUS1</td>
<td>M 99/48</td>
<td>Mauritius</td>
<td>AJ606085</td>
</tr>
<tr>
<td>PER-YL1a</td>
<td>H50-7209</td>
<td>Peru</td>
<td>AM072752</td>
</tr>
<tr>
<td>PER-YL1b</td>
<td>H50-7209</td>
<td>Peru</td>
<td>AM072753</td>
</tr>
<tr>
<td>PHL1</td>
<td>VMC76-16</td>
<td>Philippines</td>
<td>AM072628, AM072628</td>
</tr>
<tr>
<td>BRA2</td>
<td>RB83-5054</td>
<td>Brazil</td>
<td>AM072623</td>
</tr>
<tr>
<td>BRA1</td>
<td>SP83-5073</td>
<td>Brazil</td>
<td>AJ606086</td>
</tr>
<tr>
<td>SCYLV-A</td>
<td>CP65-357</td>
<td>Texas</td>
<td>AF157029</td>
</tr>
<tr>
<td>SCYLV-Ind</td>
<td>–</td>
<td>India</td>
<td>AY236971</td>
</tr>
<tr>
<td>CHN-YL1</td>
<td>CGT63-167</td>
<td>China</td>
<td>AM072751</td>
</tr>
<tr>
<td>Taiw1</td>
<td>ROC11</td>
<td>Taiwan</td>
<td>AJ491144, AJ491127</td>
</tr>
<tr>
<td>MYS1</td>
<td>TC4</td>
<td>Malaysia</td>
<td>AJ606084</td>
</tr>
</tbody>
</table>

* This study

Results and discussion

Sugarcane yellow leaf virus was present in all 13 varieties tested by RT-PCR with general primer pair YLS 462/111. Subsequently, separate RT-PCRs were optimised for each of the three genotypes (BRA-PER, CUB and REU). Using the 61°C annealing temperature as utilised by Abu-Ahmad et al. (2006), only the BRA-PER and CUB genotypes could be amplified with their respective primers. Further optimisation was required for the REU fragment and the final annealing temperature chosen was 57°C for successful amplification of the REU fragment using REU-F/B-REV.

Using the optimised RT-PCR, the presence of all three genotypes of SCYLV was confirmed in the variety collection plot, with amplification of a fragment of 362 bp, 450 bp and 905 bp representing the BRA-PER, CUB and REU genotypes respectively (Figure 1a,b,c). Genotype REU was observed in 10 varieties (Figure 1c), 4 varieties were infected with BRA-PER genotype (Figure 1b), and CUB genotype was present only in variety Co6304 (Figure 1c). Two varieties were co-infected with two genotypes of SCYLV, notably REU/BRA-PER (variety Q88, Lane 9) and CUB/REU (variety Co6304, Lane 4).

The PCR fragments from the three genotypes were cloned and sequenced (BRA-PERmu from PR67245-363 bp, CUBmu from Co6304, 452 bp and REUmu from S17-905 bp). Blast sequence analysis confirmed the occurrence of the BRA, CUB and REU genotypes in Mauritius. The BRA-PERmu fragment shared highest homology with isolate Taiw1 (AJ491144, BRA genotype), while the CUBmu fragment shared > 99% similarity with isolate CUB-YL1 (AM083988) and similarly for REUmu and REU-YL2 (AM072756).

Sequences of the genotypes from this study and those retrieved from Genbank were compared and a phylogenetic tree constructed for fragment CUB (Figure 2). The CUBmu genotype clustered with the CUB-YL1 genotype (Var C132-81) from CUBA and diverged from other genotypes of SCYLV. Abu-Ahmad et al. (2006a) analysed the amino acid identity of part of the open reading frame I of this genotype and compared with BRA, PER and REU. The CUB-YL1 genotype shared only 77–80% amino acid sequence identity with other genotypes prompting the suggestion of occurrence of a new virus.
Fig. 1—Amplification of fragments of three genotypes of SCYLV. (a- BRA-PER, b- CUB and c- REU genotypes). Lanes 1–13 are sugarcane varieties as per Table 1, lane 14 is an extract from a disease free sugarcane plantlet, lane 15 is water control and M is 100 bp molecular weight marker, Roche).

Variety Co6304 (infected with CUB genotype) was introduced in 2003 in Mauritius from India and recent studies have confirmed the presence of isolate CUB in India (Viswanathan et al., 2008). Studies of Abu-Ahmad et al. (2006b) showed the geographical grouping of SCYLV genotypes and implied different virus introduction and evolution histories in the respective environments.

SCYLV diversity in Mauritius may be more complex as a Mauritian isolate, MUS1, was previously found not to cluster with the three groups (Abu-Ahmad et al., 2006a). This is also supported by the existence of the three genotypes in the variety collection plot observed in the present study. In recent tests of local cultivars, only isolates BRA-PER and REU have been recorded, but there is a need to establish more precisely the diversity of SCYLV present by
screening a larger number of samples. Variations in virulence and infection capacity of SCYLV genotypes exist, as well as reaction of different varieties to the virus. It is necessary to investigate further the nature of the variation of SCYLV and its impact on sugarcane cultivation in Mauritius. For instance, SCYLV has also been detected in the aphid *Melanaphis sacchari* (MSIRI, 2008), and it would be of epidemiological interest to characterise the genotype(s) harboured by this vector.

![Diagram of SCYLV isolates]

**Fig. 2**—Neighbour-joining tree of SCYLV isolates. The CUB-mu fragment (This study) cluster with genotype CUB-YL1.

**Conclusions**

The present study confirmed the occurrence of three genotypes of SCYLV in a sugarcane germplasm collection in Mauritius. During an initial screening of commercial fields, the REU and BRA-PER genotypes have been found predominant while the CUB genotype detected in this study is from a germplasm collection. Further investigations are warranted for a more precise assessment of the distribution of the genotypes, their epidemiology and their impact on yield.
REFERENCES


LA PRÉSENCE DE TROIS GÉNOTYPES DU SUGARCANE YELLOW LEAF VIRUS (SCYLV) DANS UNE COLLECTION VARIÉTALE À MAURICE

Par

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MOTS-CLÉS: Canne à Sucre, SCYLV, Génotypes, Diversité Génétique.

Résumé

QUOIQUE LE Sugarcane yellow leaf virus (SCYLV) est très répandu à Maurice, les génotypes du virus n'ont pas été déterminés. Des amorces RT-PCR ont été utilisées pour identifier la diversité génétique du virus dans treize variétés infectées provenant d’une collection variétale. Les acides nucléiques totaux extraits à partir des feuilles des treize variétés ont été soumis à un test RT-PCR en deux étapes. Le protocole a été optimisé pour chaque génotype avec les paires d'amorces spécifiques CUB-F/CUB-R, REU-F/B-REU et PER-F/PER-R. Trois génotypes de SCYLV notamment BRA-PER, CUB et REU ont été confirmés dans les variétés testées. Le génotype REU a été observé dans 10 variétés tandis que 4 variétés étaient infectées par le génotype BRA-PER. Une infection mixte causée par les génotypes CUB et REU a été observée dans la variété Co6304, tandis que la Q88 était co-infectée par les génotypes BRA-PER et REU. Les produits d’amplification de 363 pb (BRA-PER), 452 pb (CUB) et 905 pb (REU), provenant des variétés PR67245, Co6304 et S17 respectivement, ont été clonés et séquencés. Les trois séquences analysées par l’algorithme Blast démontrent de fortes homologies avec les génotypes correspondants du SCYLV dans Genbank; pour le génotype BRA, 100% de similarité avec Taiwl (AJ491144), et plus de 99% de similarité avec les isolats CUB-YL1 (AM083988) et REU-YL2 (AM072756) respectivement. Récemment les génotypes REU et BRA-PER ont été révélés dans des variétés commerciales, d’où la nécessité de faire des prospections intensives au champ pour évaluer la répartition des différents génotypes de SCYLV à Maurice.
EXISTENCIA DE TRES GENOTIPOS DE VIRUS DE HOJA AMARILLA DE LA CAÑA DE AZÚCAR EN UNA COLECCIÓN DE VARIEDADES DE MAURICIO

Por

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PALABRAS CLAVE: Caña de Azúcar, SCYLV, Genotipos de Virus, Diversidad de Virus.

Resumen

El virus de la hoja amarilla de la caña de azúcar (SCYLV, por sus siglas en Inglés) está ampliamente distribuido en Mauricio, pero al momento la caracterización de genotipos del virus no ha sido determinada. Iniciadores (primers) de RT-PCR fueron usados para identificar la diversidad genética del virus en una parcela con una colección de variedades. Los ácidos nucleicos completos se extrajeron a partir de las hojas de una trece variedades introducidas, infectadas por el SCYLV, y se evaluaron con una RT-PCR de dos pasos optimizada para cada uno de los pares de iniciadores específicos de los tres genotipos (CUB-F/CUB-R, REU-F/B-REU, y PER-F/PER-R). La presencia de los tres genotipos de SCYLV, en específico BRA-PER, CUB y REU, se confirmó en la colección de germoplasma. El genotipo REU fue observado en 10 variedades, en tanto que 4 fueron infectadas por el genotipo BRA-PER. La infección mixta de genotipos CUB y REU fue observada en la variedad Co6304, mientras que Q88 fue co-infectada con los genotipos BRA-PER y REU. Los fragmentos derivados de la PCR de 363 pares de base (bp) (BRA-PER), 452 pb (CUB), 905 pb (REU) fueron amplificados de las variedades PR67245, Co6304 y S17, clonándose y secuenciándose. El análisis Blast de estas tres secuencias mostró gran homología con las secuencias de genotipo correspondientes en la base de datos "Genbank" - 100% en sínimilitud con el aislado Taiwl (AJ491144, genotipo BRA), y > 99% en sínimilitud con los aislados CUB-YL1 (AM083988) y REU-YL2 (AM072756), respectivamente. La reciente criba de algunos cultivares comerciales reveló una infección por los genotipos REU y BRA-PER. Inspecciones intensivas adicionales serán conducidas para los tres genotipos de SCYLV en campos de caña de azúcar de Mauricio.
MAPPING OF SUGARCANE VARIETY M 134/75
USING EST-SSR MARKERS

By

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KEYWORDS: EST-SSR, Linkage Map, Sugarcane And Yellow Spot Disease.

Abstract

The construction of sugarcane linkage maps has been largely limited to the use of non-genic marker systems like AFLP and genomic SSRs. Moreover, map comparison among the Saccharum genus has been hampered by the lack of common markers. In this study, an AFLP- and genomic SSR-based linkage map of sugarcane variety M 134/75 consisting of 95 linkage groups (LGs) was enhanced with genic marker systems in order to further dissect the sugarcane genome and to enable intra- and inter-species genome comparisons. The ultimate aim of this project is to identify markers linked to the yellow spot disease resistance QTL and their introgression into sugarcane marker assisted breeding. The mapping parents M 134/75 and R 570 were screened with 25 sugarcane and 425 sorghum EST-SSR primers. On average, 1.5 polymorphic bands were detected for M 134/75 with sugarcane EST-SSR primers. Two hundred and ninety-one sorghum EST-SSR primers were found polymorphic for the mapping parent M 134/75, with an average of 2.6 polymorphisms per primer. The progeny population of 226 individuals was screened with five sugarcane and 37 sorghum EST-SSR primers. One hundred and two single dose coding markers were combined with 985 available non-coding markers and analysed by GMendel to produce a partial map of M 134/75 containing 143 linkage groups (LGs). This enabled integration of 58 sorghum EST-SSR markers into 26 LGs. Based on common SSRs, LGs were grouped into ten homologous groups (HGs), among which four contained sorghum EST-SSRs. LG 68 containing the yellow spot resistance QTL was equated to HG VIII and was enhanced by three sorghum markers. Comparative mapping will be exploited to fine-map the yellow spot disease resistance QTL.

Introduction

The construction of sugarcane linkage maps has been largely limited to the use of non-genic marker systems like AFLP and genomic SSRs (gSSR). Intra-species and intra-genus comparisons have not been possible using these markers, as they were non-coding and locus unspecific.

Over the past decade, there has been an exponential increase in the availability of expressed sequence tags (EST) sequence data from a wide variety of taxa.

This abundance of EST sequences has become an attractive potential source of microsatellite markers after the findings that gene transcripts can also contain SSRs (Kantety et al., 2002). Deriving SSR markers from EST sequences (EST-SSRs) has an intrinsic advantage over gSSR because they can be easily obtained by data mining of EST databases.

This is a much cheaper alternative to the conventional isolation and characterisation of gSSRs via DNA libraries and is also less time consuming. The usefulness of these genic SSRs also lies in their cross-species transferability because the primers are from coding sequences that are more conserved across species. These EST-SSRs are also useful as anchor markers for comparative
mapping and have the added advantage of being directly associated with traits of interest. Hence, they provide a more targeted approach to identification of markers linked to genes or quantitative trait loci (QTL).

Over the past few years, several projects for the sequencing of sugarcane ESTs have been initiated in South Africa (Carson et al., 2000), Brazil (http://sucest.lad.ic.unicamp.br/en/) and Australia (Casu et al., 2001), allowing the development of EST-SSRs for the Saccharum genus (Cordeiro et al., 2001; Pinto et al., 2004).

The application of sugarcane EST-SSR for diversity studies has been previously reported (Cordeiro et al., 2001), but its use in genetic mapping of sugarcane has only been recently reported (Oliveira et al., 2007). In this work, 149 EST-SSRs were used in the construction of an integrated sugarcane map derived from a cross between Brazilian hybrid cultivars SP80-180 and SP80-4966. Combined with RFLP and AFLP marker data, a linkage map was constructed containing 149 functionally associated EST-SSR markers scattered among 79 LGs.

At the Mauritius Sugar Industry Research Institute (MSIRI), emphasis is being placed on the integration of marker assisted selection (MAS) into its sugarcane breeding program. The aim of this study is to identify markers linked to putative sugarcane yellow spot (YS) disease resistance gene(s).

This is a major disease of sugarcane and can account for 10–25% reduction in sucrose content among susceptible varieties grown in the superhumid zones of Mauritius. It is caused by the fungus Mycovellosiella koepkei. The selection for resistant varieties in the current breeding program is costly, time-consuming and not fully reliable as disease expression is dependent on abiotic factors such as weather conditions and high disease pressure.

In a previous study (Aljanabi et al., 2007), a population of 227 progenies derived from a biparental cross between a yellow spot disease resistant parent (M 134/75) and a susceptible parent (R 570) was screened with AFLP and gSSR. A genetic linkage map was constructed for variety M 134/75 containing 95 LGs onto which 567 single dose markers were mapped.

Field disease resistance data of the mapping population scored over two ratoon crops coupled with molecular marker data enabled the identification of a major quantitative trait locus (QTL) responsible for 23.8% field phenotypic variation in the trait. This QTL is flanked on one side by an AFLP marker actctc10 and an SSR marker mSSCIR12284 at 14 cM and 18 cM respectively. These markers are, however, not close enough to the yellow spot QTL to validate their use in sugarcane MAS. The ultimate aim of this project is to identify markers located at approximately 5 cM to this QTL that can be used for MAS.

Map enhancement of M 134/75 was thus considered from a set of sugarcane EST-SSR primers (sequences, kindly provided by E. Ulian). The use of orthologous EST-SSR was also investigated to facilitate the comparative mapping of sugarcane to closely related species. The most appropriate candidate is sorghum, which diverged from a common ancestor 8–9 million years ago (Jannoo et al., 2007). Sorghum RFLP probes have been previously used in sugarcane mapping and have shown perfect synteny with sugarcane (Guimares et al., 1997; Ming et al., 1998). The application of EST-SSR marker systems to the linkage mapping of sugarcane is thus being reported.

**Materials and methods**

DNA was extracted from mapping parents M 134/75 and R 570 and their 226 mapping progeny population as described by Aljanabi et al. (1999). Resuspended DNA was diluted to 20 ng/µL for further use.

**Sugarcane EST-SSR PCR**

The mapping parents M 134/75 and R 570 were screened with 25 sugarcane EST-SSR primers by PCR in 20 µL reaction volumes using the following conditions; 1X reaction buffer
(Roche), 0.4 µM dNTPs (Roche), 1 unit Taq polymerase (Roche), 0.4 µM forward primer, 0.4 µM $^{33}$P labelled reverse primer and 50 ng DNA template. PCR conditions were as follows: an initial denaturation at 94°C for 3 min followed by 32 cycles at 94°C, annealing at 54°C and extension at 72°C each for 1 min and a final extension at 72°C for 5 min.

Selected polymorphic primers (5) were used to genotype the mapping population. PCR products were run for 2 h on 6% polyacrylamide gels, pre-warmed at 60°C. Gels were blotted on filter paper, vacuum dried and exposed to X-ray films (Kodak X-OMAT). Depending on the intensity of the $^{33}$P signal, films were developed 2–5 days after exposure.

**Sorghum EST-SSR primer testing**

Two sets of sorghum EST-SSR were used, 30 primer pairs (SOR1-30) previously used in a cross-species transferability study (Wang *et al.*, 2005) and 600 primer pairs (SAT0100-SAT1250) from ICRISAT (sequences kindly provided by Dr T. Hash) were initially tested for cross-species transferability at an annealing temperature of 50°C by PCR in 20 µL reaction volumes using the same reaction mix as above.

PCR conditions were as follows: an initial denaturation at 94°C for 3 min followed by 32 cycles at 94°C for 45 s, annealing at 50°C for 45 s and extension at 72°C each for 30 s and a final extension at 72°C for 5 min. The PCR products were run on agarose gels (2%) and visualised over a UV transilluminator after staining with ethidium bromide.

The SOR primers were screened for polymorphism with the mapping parents and five selected primers were used for population genotyping. The SAT primers were also tested for cross-species transferability and 425 initially selected primers were used to assess the level of polymorphism between the mapping parents.

Thirty-two out of 134 primers showing distinct profiles with prominent bands were further used for population genotyping on polyacrylamide gels.

**Marker scoring and nomenclature**

A pseudo-testcross strategy was followed to score the polymorphisms (Grattapaglia and Sederrof, 1994). The bands were scored for the presence or absence when heterozygous in M134/75, null in R570 and segregating progeny population.

Each marker was given a unique identifier as follows: the first three letters referred to the origin of the primer; SOR or SAT. For SOR markers, the next digit or two digits referred to the primer number (1–30) and the last digit referred to the allele number (eg SOR 202 refers to allele number 2 from primer SOR20). For ICRISAT markers, the 4 digits next to SAT referred to the primer number and the last digit referred to the allele number.

Alleles from the same primer were numbered according to the position of the marker on the gels depending on their molecular weights. The highest molecular weight polymorphic marker was named as *Primername1* and sequentially increased by one unit with decreasing sizes.

Likewise, sugarcane EST-SSR markers were named according to the name of the primer ESTSC or ESTD followed by the allele number. AFLP and gSSR markers nomenclature was as described as Aljanabi *et al.* (2007).

**Linkage map construction and homology grouping**

A chi-square test was performed to select for single dose markers i.e those segregating in a 1:1 ratio. GMendel (Holloway and Knapp, 1994) from iMAS platform (an integrated marker assisted selection software [http://localhost:8080/iMAS](http://localhost:8080/iMAS)) was used for linkage map construction.

All markers with more than 15% missing values and genotypes (5) missing at >15% were excluded from the analysis. Two-point analyses between single dose markers were performed at a LOD score threshold of five and recombination fraction threshold of 0.30. Markers within each
linkage group (LG) were then ordered by using the Kosambi mapping function. The LGs were graphically represented using Mapchart 2.1 (Voorrips, 2002). LGs were pooled into the same HGs when they had at least two common SSR markers.

A number of LGs with only one common SSR marker were grouped into unassigned HGs (UAHG). The nomenclature of the HGs was in accordance to Rossi et al. (2003) whenever possible.

**Results**

Among the twenty-five sugarcane EST-SSR primers, only 12 primers (48%) were found polymorphic. The average level of polymorphism for the resistant parent M 134/75 was only 1.5 as compared to 2.0 for gSSR (unpublished data). Twelve markers were scored after genotyping with five EST-SSR primers.

All SOR primers were transferable to sugarcane as observed on agarose following amplification, whereas 95% of SAT primers correspondingly amplified an orthologous target in sugarcane.

As compared to sorghum, sugarcane amplification with sorghum EST-SSR primers showed a more complex profile.

A higher number of amplicons and a wider distribution of amplicons along the gels were observed when sorghum primers were used on sugarcane. In most cases, the level of polymorphism is higher in sugarcane than in sorghum probably due to the higher ploidy level of the sugarcane genome.

There was also no apparent size correlation between sorghum and sugarcane amplicons (data kindly provided by R. Punna, ICRISAT).

Sixteen SOR primers produced markers polymorphic to M 134/75 revealing an average 2.3 polymorphisms. Among the 425 SAT primers screened, 275 primers were found polymorphic for the resistant parent M 134/75. These revealed 712 polymorphisms averaging 2.6 polymorphisms per primer.

The 32 SAT primers used to genotype the mapping population revealed 102 polymorphisms. These were combined with 13 SOR markers and 12 sugarcane EST-SSR markers. The 127 markers were trimmed to 102 markers segregating into a 1:1 ratio. These data were pooled with existing 985 non-coding AFLP and gSSR primers to produce a combined marker data set of 1087 markers.

The final data were analysed by GMendel from iMAS. A partial genetic map of sugarcane hybrid cv M 134/75 was produced containing 640 markers, 143 LGs and with a total map length of 9530 cM. Among these, 58 EST markers were mapped into 26 LGs, 8 of which (30%) contained solely EST-SSR markers.

Grouping of LGs into homologous groups was carried out according to Rossi et al. (2003) whenever applicable. Using this nomenclature system, LGs belonging to HG I, II, III, VI, VII and VIII were identified and assigned to their respective HG.

No grouping was possible into HG IV and HG V since no mSSCIR marker (Table 1) has been assigned to these HGs. Using the system of grouping of LGs containing at least two common SSR markers, four additional HGs were identified, HG IX –HG XII. LGs containing only one common SSR marker were classified into five unassigned HGs (UAHG 1-UAHG 5).

This method of nomenclature enabled classification of EST-SSR from 26 primers into four HGs, II, III, VIII and X.

Markers from only two primers were shared between HGs i.e markers SAT0918 and SAT0203 were present in both HG II and HG VIII.

Twenty-two LGs were classified into HG VIII, which represented the highest frequency found in any HG.
Table 1—Classification of LGs according Rossi et al. (2003) and identification of EST-SSR markers belonging to their respective HG. (Classification according to: a = Rossi et al., 2003, b = Aljanabi et al. 2007, na = not available).

<table>
<thead>
<tr>
<th>mSSCIR</th>
<th>Initial M 134/75 HG (b)</th>
<th>New M 134/75 HG</th>
<th>M 134/75 mSSCIR (if any)</th>
<th>M 134/75 EST-SSR</th>
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<tbody>
<tr>
<td>I</td>
<td>14, 19, 27, 42, 52, 53</td>
<td>II</td>
<td>I</td>
<td>19</td>
</tr>
<tr>
<td>II</td>
<td>34, 35, 39, 41, 48</td>
<td>XII</td>
<td>II</td>
<td>35</td>
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<td>64</td>
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<td>III</td>
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<td></td>
</tr>
<tr>
<td>V</td>
<td>n.a</td>
<td>V</td>
<td>na</td>
<td></td>
</tr>
<tr>
<td>VI</td>
<td>10, 37, 47, 54, 60</td>
<td>I</td>
<td>VI</td>
<td>60</td>
</tr>
<tr>
<td>VII</td>
<td>21, 36, 43</td>
<td>I</td>
<td>VII</td>
<td>21</td>
</tr>
<tr>
<td>VIII</td>
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<td>II</td>
<td>VIII</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>XV</td>
<td>IX</td>
<td>M1011 M1288 M2019 M1084 M1825</td>
</tr>
<tr>
<td></td>
<td></td>
<td>VI</td>
<td>X</td>
<td>11, 39 SAT0103</td>
</tr>
<tr>
<td></td>
<td>XX</td>
<td>XI</td>
<td></td>
<td>M1075HA, 1237FL, M1282FL</td>
</tr>
<tr>
<td></td>
<td>V</td>
<td>XII</td>
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<td>M 765</td>
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<tr>
<td></td>
<td>XIV</td>
<td>UAHG1</td>
<td></td>
<td>M1807</td>
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<td>XVI</td>
<td>UAHG2</td>
<td></td>
<td>M1069</td>
</tr>
<tr>
<td></td>
<td>XI</td>
<td>UAHG3</td>
<td></td>
<td>16</td>
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<tr>
<td></td>
<td>XIII</td>
<td>UAHG4</td>
<td></td>
<td>M1116</td>
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<tr>
<td></td>
<td>XI</td>
<td>UAHG5</td>
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<td>M119G</td>
</tr>
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</table>

In a previous work (Aljanabi et al. 2007), a putative QTL for resistance to yellow spot was identified on LG87 flanked by markers Actctc10 and CIR12284 (Figure 1). In this study, this LG has been enhanced with three sorghum EST-SSR markers SAT1225, SAT0203 and SAT0612 and sugarcane ESTSC2 of newly named LG68 classified into HG VIII (Figure 1).

![YS QTL](image)

Fig. 1—Map enhancement of LG 68 harbouring the YS resistance QTL with sorghum EST-SSR primers SAT1225, SAT0203 and SAT0612 and sugarcane derived EST-SSR primer ESTSC2.
Fig. 2—Synteny across sugarcane LG based on sorghum EST-SSR markers. Arrows shows marker linkage conservation between markers SAT1225, SAT0203 and SAT0612 on LG 5, LG 68 and LG 44.

Synteny across the LGs is exemplified between markers of LG 5, LG 44 and LG 68 (Figure 2). SAT0203 and SAT0612 are linked on LG 5, SAT0612 and SAT1225 are linked on LG 44. All three markers are linked on LG 68.

Discussion

The use of sugarcane EST-SSR in the genetic mapping of sugarcane has so far been reported by Oliveira et al. (2007) whereby an integrated map of sugarcane was constructed from a cross between hybrid cultivars SP80-180 and SP80-4966.

The application of sugarcane EST-SSR mapping to variety M 134/75 was investigated from a set of 25 primers. However, a low level of polymorphisms was detected between the mapping parents. From 12 sugarcane EST-SSR SDMs scored, six (50%) were successfully assigned to LGs. On average, the same percentage of integration was observed by Oliveira et al. (2007).

The use of sorghum EST-SSR in the mapping of sugarcane has not been described before. Documentation is available mostly on cross-transferability studies and their potential use in diversity studies and linkage mapping. In a similar study (Wang et al., 2005), the transfer rate EST-SSR from hexaploid wheat to tetraploid wheat was found to be 80% despite them belonging to the same genus.

The transfer rate from sorghum to maize (both belonging to the same family –Panicoideae) was only 61%. The few sorghum EST-SSR primers (less than 5%) that could not be transferred to sugarcane could be attributed to sequence divergence between the two genera or to experimental errors. Average polymorphism level of 2.3 and 2.6 for SOR and SAT primers respectively indicated excellent potential of such orthologous marker systems applied to sugarcane mapping.

Sorghum EST-SSR primers produced a complex PCR profile with several bands when amplifying sugarcane as compared to sorghum where only 1–2 amplicons can be observed. This complexity can be attributed to the polyploid genome of sugarcane. With eight genomes contributed by *S. officinarum* and combined to the genome contributed by *S. spontaneum*, at least nine ‘homoeologous’ regions can be targeted by the primers.

Also, since target regions may vary in sequence between sorghum and sugarcane combined with a low annealing temperature (50°C), primers could be targeting non-orthologous regions adding to the complexity of the profile. Finally, variation in the number of repeats coupled with the
presence of indels/introns of different sizes across species could explain the lack of correlation in fragment size between sorghum and sugarcane.

Data from 102 single dose EST-SSR (sugarcane and sorghum) markers were combined with existing 985 non-coding AFLP and gSSR markers to produce a partial genetic map of sugarcane variety M 134/75 of 143 LGs. By grouping together LGs carrying common SSR markers as described by Rossi et al. (2003), it has been possible to equate the LGs into their respective HGs. Using this approach, LGs were assigned to HGs I, II, III, VI, VII and VIII. LGs belonging to HG IV and V were not identified due to lack of common gSSR markers. LG 68, harbouring the yellow spot disease resistance QTL was thus assigned into group VIII.

Of interest is that a sugarcane rust resistance gene was located on LG 3 of an R 570 map, which also belongs to HG VIII and where three resistance gene analogue clusters are also present (Raboin et al., 2006). Now that the location of the yellow spot disease resistance QTL has been confined to HG VIII, more effort can be channelled into the mapping of markers known to be located in this HG.

A framework of markers common to HG VIII is already available (Piperidis et al., 2008) after comparison of genetic maps of varieties Q 165, Q117 and MQ77-340 to R 570. This will be used to enhance LGs assigned to HG VIII of M 134/75 instead of targeting the sugarcane cv M 134/75 entire genome.

LG 68 harbouring the yellow spot disease resistance QTL has also been enhanced by three SAT markers i.e SAT1225, SAT0203 and SAT0612. The nomenclature of these SSR markers is based on their location on the rice chromosomes, i.e the first two digits of the primer name represents the EST location on the rice chromosome (R. Punna, personal communication).

In this respect, fragments of rice chromosomes 12, 2 and 6 could be collinear to the regions within LG 68. Channelling efforts into the mapping of a maximum of sorghum EST-SSR primers along these 3 series of primers (i.e SAT1201-1250, SAT0601-0650 and SAT0200-0250) could further enhance this LG and identify markers closer to the yellow spot gene.

However, synteny between rice and sugarcane is known to have been disrupted by a number of rearrangements and translocations (Asnaghi et al., 2000). A more accurate alternative is to identify the region into sorghum harbouring the SAT1225, SAT0203 and SAT0612 markers and eventually to describe the collinear region in the vicinity of the yellow spot gene.

A detailed study of LGs 5, 44 and 68 belonging to HG VIII provides an interesting example of the conservation of gene order among different chromosomes. LG 5 harbours markers SAT0203 and SAT0612, LG 44 links SAT1225 and SAT0612. LG 68 harbours all three SAT markers i.e SAT1225, SAT0612 and SAT0203 thus showing the conserved gene order between these three markers.

Therefore, through the use of sorghum EST-SSR markers, it has been possible to demonstrate the existence of collinearity among sugarcane homoeologous chromosomes and confirms the fact that comparative genetics remains a powerful tool to study genome organisation especially in complex polyploids like sugarcane.

Acknowledgements

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REFERENCES


L’UTILISATION DES MARQUEURS EST-SSR POUR CARTOGRAPHIER
LA VARIÉTÉ M 134/75 DE CANNE À SUCRE

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MOTS-CLÉS: EST-SSR, Carte Génétique,
Canne à Sucre, Taches Jaunes.

Résumé

La construction de cartes génétiques de canne à sucre a été largement limitée à l'utilisation des marqueurs non-géniques tels les AFLP et les SSR génomiques. En outre, la comparaison entre les cartes génétiques du genre *Saccharum* pose des difficultés en raison de l’absence des marqueurs en commun. Dans cette étude, une carte génétique de la variété M 134/75 de canne à sucre réalisée avec les marqueurs AFLP et SSR-génomiques et composée de 95 groupes de liaison a été couplée avec des marqueurs géniques dans le but de disséquer le génome de la canne à sucre et de permettre des comparaisons génomiques intra- et inter- spécifiques. Le but ultime de ce projet consiste à identifier des marqueurs liés au QTL de résistance de la maladie de taches jaunes (yellow spot) et à leur application dans la sélection assistée par marqueurs. Les parents M 134/75 et R 570 ont été criblés avec 25 amorces EST-SSR dérivées des séquences de canne à sucre. Au total 291 amorces EST-SSR-sorgho ont produit des bandes polymorphes dans la variété M 134/75, avec une moyenne de 2.6 polymorphismes par amorce. Une descendance de 226 progénitures a été évaluée avec cinq amorces EST-SSR dérivées de la canne à sucre et 37 du sorgho. Cent deux marqueurs EST-SSR qui ségréguaient selon un ratio de 1:1 (simplex) ont été couplés avec 985 marqueurs non codant et les résultats analysés à l'aide du logiciel Gmendel. Une carte partielle de la variété M 134/75 comprenant 143 groupes de liaison a été réalisée. Cela a permis l’intégration de 58 marqueurs EST-SSR du sorgho dans 26 groupes de liaison génétique. En comparant les marqueurs SSR communs, les groupes de liaison ont été rassemblés en dix groupes homologues, parmi lesquels quatre comprenaient des marqueurs EST-SSR du sorgho. Le groupe de liaison 68 sur lequel le QTL pour la résistance aux taches jaunes est présent, a été aligné avec le groupe homologue VIII (HG VIII). Trois marqueurs EST du sorgho ont aussi été placés sur le groupe de liaison 68. La cartographie comparative sera exploitée pour une cartographie fine du QTL responsable pour la résistance aux taches jaunes.
CARTOGRAFÍA DE LA VARIEDAD M 134/75 DE CAÑA DE AZÚCAR
USANDO MARCADORES EST-SSR

Por

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PALABRAS CLAVE: EST-SSR, Mapa de Ligamiento, Caña de Azúcar y Enfermedad de la Mancha Amarilla.

Resumen

LA CONSTRUCCIÓN de mapas de ligamiento de caña de azúcar ha sido limitada en gran medida por el uso de sistemas no génicos, como los AFLP y los genómicos SSR. En adición, la comparación de mapas entre el género Saccharum ha sido obstaculizado por la falta de marcadores en común. En este estudio, el mapa de ligamiento de la variedad M 134/75 de la caña de azúcar (construido con marcadores AFLP y SSR) consistente de 95 grupos de ligamiento (GL) fue mejorado con sistemas de marcadores génicos a fin de disectar, subsecuentemente, al genómio de la caña de azúcar y hacer posible comparaciones genómicas dentro y entre especies. El objetivo esencial de este proyecto es identificar marcadores asociados con los QTL de la resistencia a la enfermedad de la mancha amarilla y su introgresión en el fitomejoramiento asistido con marcadores de la caña de azúcar. La criba de los progenitores usados en la cartografía, M 134/75 y R 570, fue efectuada con 25 iniciadores (primers) EST-SSR de la caña de azúcar y 425 del sorgo. En promedio, 1.5 bandas polimórficas fueron detectadas para el M 134/75 con iniciadores EST-SSR de la caña de azúcar. Doscientos noventa EST-SSR iniciadores de sorgo fueron identificados como polimórficos para el progenitor M 134/75, con un promedio de 2.6 polimorfismos por iniciador. La progenie que constituyó la población de 226 individuos fue evaluada con cinco iniciadores EST-SSR de la caña de azúcar y 37 de sorgo. Ciento dos marcadores que codifican para una sola secuencia fueron combinados con 985 marcadores de no codificación que se encontraban disponibles, los cuales fueron analizados con la aplicación GMendel para producir un mapa parcial de M 134/75 constituido por 143 GL. Esto hizo posible la integración de 58 marcadores EST-SSR de sorgo con 26 GL. Con base en los SSR en común, los GL fueron agrupados en diez grupos homólogos (GH), entre los que se encontraban cuatro EST-SSR de sorgo. Los 68 GL que contenían los QTL de resistencia a la mancha amarilla fueron equiparados al GH VIII, el cual fue adiciona con tres marcadores del sorgo. La cartografía comparada será aprovechada en la cartografía fina de los QTL de la resistencia a la enfermedad de la mancha amarilla.
THE SUCEST-FUN REGULATORY NETWORK DATABASE: DESIGNING AN ENERGY GRASS

By

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KEYWORDS: Sugarcane, SUCEST-FUN Database, Bioinformatics, Genome Sequence, Transcriptome, Regulation.

Abstract
Modern sugarcane cultivars are complex hybrids resulting from crosses among several Saccharum species. Traditional breeding methods have been employed extensively in different countries over the past decades to develop varieties with increased sucrose yield and resistance to pests and diseases. Conventional variety improvement, however, may be limited by the narrow pool of suitable genes. Thus, molecular genetics is seen as a promising tool to assist in the process of developing improved varieties. The SUCEST-FUN Project (http://sucest-fun.org) aims to associate function with sugarcane genes using a variety of tools, in particular those that enable the study of the sugarcane transcriptome. An extensive analysis has been conducted to characterise, phenotypically, sugarcane genotypes with regard to their sucrose content, biomass and drought responses. Through the analysis of different cultivars, genes associated with sucrose content, yield, lignin and drought have been identified. Currently, tools are being developed to determine signalling and regulatory networks in grasses, and to sequence the sugarcane genome, as well as to identify sugarcane promoters. This is being implemented through the SUCEST-FUN (http://sucest-fun.org) and GRASSIUS databases (http://grassius.org), the cloning of sugarcane promoters, the identification of cis-regulatory elements (CRE) using Chromatin Immunoprecipitation-sequencing (ChIP-Seq) and the generation of a comprehensive Signal Transduction and Transcription gene catalogue (SUCAST Catalogue).

Introduction
The increased importance of sugarcane as a bioenergy feedstock has increased pressure to generate new varieties optimised for energy production. The generation of improved varieties has relied largely on traditional breeding methods, which is limited by the narrow pool of suitable genes and the time-consuming process of selection of plants with desired agronomic traits. In this sense, molecular genetics can assist the process of developing improved varieties by generating molecular markers that can be used in the breeding process or by introducing new genes into the sugarcane genome (Menossi et al., 2008).

In the last few years, the use of many high-throughput methods has exponentially increased the amount of data available to molecular geneticists. As a result, bioinformatics and efficient data management are essential in order to generate useful information. Furthermore, most of the available biological data are complex and stored in dozens of smaller databases (Lacroix and Critchlow, 2003). These databases are frequently not easy to identify and integrate, making the use of information very difficult because of the variety of semantics, interfaces, and data formats used by the underlying data sources (Lacroix and Critchlow, 2003).
The aim of this paper is to describe the SUCEST-FUN Regulatory Network Database (CaneRegNet), which contains data and tools of interest for sugarcane functional genomicsists and molecular breeders. This database has been developed in the concept of the mediator approach that incorporates concepts from Data Warehouse and Federation approaches (Lacroix and Critchlow, 2003). It also has flexible data integration to assemble heterogeneous distributed data sources, experimental data, resources, the applications of scientific algorithms and computational analysis.

The database community has extensively investigated architectures and tools for data integration (Lacroix and Critchlow, 2003). A key disadvantage of the warehouse approach is the need for local administrators to maintain the data, while providing control over the contents of the warehoused data. Mediators and heterogeneous Database Management Systems (DBMS), on the other hand, submit the queries directly to the wrappers; program routines that take data from Internet websites or any other data repositories and convert the information into a structured format, and integrate the results locally (Boulcelma et al., 2003).

A geographic data warehouse must provide an expressive query language that may be difficult to maintain and less expressive than those available at remote sources. On the other hand, non-materialised approaches must not only integrate data, but also support all these query capabilities of interest. The purpose of the mediator approach is to integrate both data and source capabilities.

**Methods**

The databases were developed using MySQL Server (http://www.mysql.com) while the interface and search systems were based on the WebServer Apache (http://www.apache.org).

The website uses the Joomla platform, as a Content Management System. This platform is developed using PHP (server-side HTML-embedded scripting language). Both Joomla and PHP are free software released under the GNU/GPL Licence. Joomla provides a more interactive website, which allows keyword searches and also manages the access control for groups of users. Moreover, Joomla has a toolkit that provides flexibility in the integration of scripts and programs developed in other languages.

The tools and scripts developed and implemented in the website were produced using CGI (Simple Common Gateway Interface Class), PHP (http://www.php.net), PERL (http://www.perl.org) and R (http://www.r-project.org) a statistical environment. The data are available to the SUCEST-FUN community through the integration of other platforms such as the Gbrowse (Generic Genome Browse – http://www.gmod.org) and BioPerl (Stajich et al., 2002) modules.

**Results**

The CaneRegNet has been developed following the concept of the mediator approach, which integrates concepts from the Data Warehouse and the Federation approaches. Accessed data are up-to-date, but access can be costly. In addition, wrappers (Boulcelma et al., 2003) must be maintained since data providers may change the entry points to the data sources as well as the database organisation. Neither materialised into data warehouses nor non-materialised approaches address the problem to access or maintain sophisticated tools that enhance data manipulation. Indeed, in addition to standard data manipulation such as those performed by SQL, geographic languages usually express spatial selections, metric or topological queries and allocations among other features (Boulcelma et al., 2002).

The SUCEST-FUN Regulatory Network Database (CaneRegNet) assembles different sugarcane databases such as the SugarcaneExpressed Sequence Tags (SUCEST) Genome Project (http://sucest.lad.ic.unicamp.br/en/) (Vettore et al., 2003), the SUCAST and the SUCAMET Catalogues, which include expression data (http://sucest-fun.org), the GRASSIUS database (Yilmaz et al., 2009) and records of the agronomic, physiological and biochemical characteristics of
sugarcane cultivars. This database is part of the SUCEST-FUN Regulatory Network Project (http://sucest-fun.org), which aims to study gene expression regulation through the use of tools that will allow a System Biology approach for the study of sugarcane. This database is based on five main topics: 1) Gene annotation, 2) Gene Expression, 3) Public Resources, 4) Sequencing Projects and 5) Functional Genomics (Figure 1).

Fig. 1—Diagram of the CaneRegNet database and data abstraction. The CaneRegNet is based on five main topics: Gene Annotation, Gene Expression, Public Resources, Sequencing Projects and Functional Genomics. The topics and source arrows are bidirectional allowing the interaction and relationship between them. TFs stand for Transcription Factors.

1) Gene Annotation

The Gene Annotation resource integrates the many catalogues generated from the annotation and categorisation of the putative transcripts sequenced by the SUCEST project (http://sucest.lbi.ic.unicamp.br/public/), which is the largest sugarcane EST collection and is represented by 43,141 putative transcripts known as the Sugarcane Assembled Sequences (SAS).

The SUCAST Catalogue (Sugar Cane Signal Transduction—http://sucest-fun.org/cane_regnet/en/database-tools/gene-catalogue/sucast-catalogue) is the first characterisation of the putative transcripts sequenced by the SUCEST project.

It contains more than 3500 components involved in several aspects of signal transduction, transcription, development, cell cycles, stress response and pathogen interaction (Souza et al., 2001).

The SUCAST Catalogue Tool allows the search of genes by categories and contains genes involved in signal transduction pathways that integrate with the sugarcane kinome based on a phylogenetic categorisation (Rocha et al., 2007).

The SUCAMET Catalogue (Sugar Cane Metabolism) contains genes involved in metabolic pathways. As in the SUCAST Catalogue, the SUCAMET Catalogue Tool was developed to enable the search for genes by categories.

Both the SUCAST and SUCAMET projects were used to generate cDNA-arrays for the study of the sugarcane transcriptome.

More recently, a Cell Wall Catalogue and a Transcription Factor Catalogue were included in the CaneRegNet. The Transcription Factor Catalogue was generated as part of a collaborative effort.
to develop the GRASSIUS Platform (Grass Regulatory Information Services) (Yilmaz et al., 2009). GRASSIUS holds information on transcription factors (TFs) from maize, sorghum, sugarcane and rice classified into families.

The TFs for grasses can be accessed by either browsing family members or searching by name or by sequence similarity through BLAST searches or by phylogenetic homology. The GRASSIUS Platform contains 1647 TFs catalogued for sugarcane, which represents about 83% of the number estimated to be present in sugarcane (Yilmaz et al., 2009).

The identification of sugarcane TFs is an essential step in the process of building regulatory networks, which also requires the identification of promoters, CREs and knowledge on their interactions with TFs (Schlitt and Brazma, 2007).

2) Gene Expression

The Gene Expression resource is focused on the comparison of the expression profile of different sugarcane varieties, different tissues within one individual and individuals subjected to different biotic and abiotic stimuli.

The expression profiles were made from two different custom cDNA microarrays. One cDNA microarray contained 2208 elements from the SUCAST Catalogue and was designed to identify the transcriptome changes in response to drought, phosphate starvation, stress in response to herbivory and N2-fixing endophytic bacteria.

Also investigated was the response of sugarcane to phytohormones, such as abscisic acid (ABA) and methyl jasmonate. The other cDNA microarray (SUCAMET Catalogue) contained 4594 elements that are involved in cellular process, stress response and basal metabolism.

An outliers searching method resulted in the identification of 179 genes that were considered differentially expressed in at least one of the treatments analysed (Rocha et al., 2007). qRT-PCR was used to validate the expression profiles obtained using the cDNA arrays.

Expression data were stored in different stages and formats in flat files and Relational Databases, which can be visualised and grouped by correlation, Venn diagrams or experiments using different cut-offs and levels of confidence. The analysis of both cDNA arrays resulted in the development of several tools that allow the search for differentially expressed genes. For example, a virtual Matrix of expression profile by tissues was constructed using data from the SUCAST microarray, which allowed the identification of sugarcane genes that are tissue specific.

Furthermore, a Self Organising Map (SOM) tool was implemented to select differentially expressed candidate genes to make hierarchical clustering analysis (Rocha et al., 2007). The Gene Expression database in CaneRegNet allows the identification of genes that are co-regulated by different treatments.

For example, a comparison between the transcripts from sugarcane treated with 100 μM ABA and those present in drought tolerant and drought sensitive sugarcane varieties subjected to water deficit stress showed that 14 of the 24 genes differentially regulated by ABA also had different expression levels in one of the sugarcane varieties.

In addition, 115 of the 184 genes regulated in tolerant varieties submitted to drought were also differentially expressed in sensitive varieties (Figure 2). Among the ABA treatment and the drought tolerant varieties submitted to drought and between ABA treatment and drought sensitive varieties, the four gene categories that were more represented included stress, carbohydrate metabolism, hormone biosynthesis and no matches.

Eleven genes were differentially expressed in the three samples. These genes belonged to stress, carbohydrate metabolism, hormone biosynthesis, no matches, protein phosphatase and unknown protein functional categories.

Another example of co-regulation has recently been described for genes associated with sucrose content and drought responses (Papini-Terzi et al., 2009).
Fig. 2—Comparison of differential gene expression associated with ABA treatment and drought stress in sugarcane. Genes were identified as associated with ABA if they were differentially expressed when treated (for 0.5, 1, 6 and 12 h) and untreated plants were compared. Genes regulated during drought stress were identified by comparing plants with irrigation and without irrigation after 24, 72 or 120 h of water deficit. The figure represents a Venn diagram of the three differential expression data sets. The credibility level used to define outliers was 0.96 in all three data sets.

A new platform 60-mer Agilent oligoarray technology with a custom-designed array (44k = 44 000 elements) has been developed recently to improve the investigation of the sugarcane transcriptome. Approximately 40% of the unique genes in the SUCEST database are represented in this array, with a total of 21 902 specific probes replicated twice and designed in the sense and antisense direction with high specificity. This oligoarray will allow the identification of antisense expressed sequences and the sugarcane regulatory networks associated with sucrose content and drought stress.

3) Public Resources

A great number of databases and resources have been developed for general genome analysis, such as the National Center for Biotechnology Information (NCBI), Gene Ontology (GO)(Ashburner and Lewis, 2002) and Kyoto Encyclopedia of Gene and Genomes (KEGG) (Kanehisa and Goto, 2000), and for the study of grass genomes, such as MaizeGDB (Lawrence et al., 2004) Sorghum Phytozome (Paterson et al., 2009) and Rice Genome Annotation (Yuan et al., 2003). These databases allow the integration of a variety of data types and analyses in a single framework. The flexibility of these generic data abstractions will allow the integration of all data and joint analysis of sugarcane and other grasses, and will provide a simple and fast searching platform.

4) Sequencing Projects

The CaneRegNet database contains the sequences produced by the SUCEST Project (http://sucest.lad.ic.unicamp.br/en/; (Vettore et al., 2003). This project produced 237 954 high quality ESTs, obtained from 27 cDNA libraries from different sugarcane tissues of different developmental stages and stress conditions. This collection of ESTs was assembled into 43 141 putative genes referenced as Sugarcane Assembled Sequences (SAS) that can be analysed with the following tools:

- **Tissue and Library Search**—gives access to the names, descriptions and EST sequences by library or tissue specific
- **Cluster alignment viewer**—shows the cluster assembly of an EST
- **Object Search**—permits direct access to any object, such as ESTs or a SAS name
• **Generic SQL Query**—allows users to create generic queries typed in a web form and the results are exhibited in a tabular format

• **SAS Information Viewer**—integrates and exhibits all SAS information available in the CaneRegNet database.

Sugarcane and sorghum are syntenic organisms that show co-linearity between the genes and striking homology in most of the coding parts of the genome (Jannoo *et al.*, 2007). When SUCEST was compared with the sorghum CDS sequences using the pairwise alignments, 4212 orthologue candidates were identified (Table 1). These putative orthologues were identified using stringent parameters of e-value, coverage and identity. Because SAS are expected to contain UTRs and some of them are incomplete transcripts, a more rigorous coverage threshold was applied to sorghum. Less stringent parameters may result in a larger number of candidates, at the cost of increase in false positives.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Lowest value</th>
<th>Median</th>
<th>Highest value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAS length (nt)</td>
<td>262</td>
<td>1304</td>
<td>6194</td>
</tr>
<tr>
<td>Sorghum CDS length</td>
<td>153</td>
<td>933</td>
<td>3417</td>
</tr>
<tr>
<td>Sorghum coverage</td>
<td>90%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>SAS coverage</td>
<td>50%</td>
<td>70%</td>
<td>100%</td>
</tr>
<tr>
<td>% identity</td>
<td>79%</td>
<td>96%</td>
<td>99%</td>
</tr>
</tbody>
</table>

A number of SAS (19,418) were mapped onto the sorghum genome using tools that allowed the identification of intron/exon boundaries spanning 10 chromosomes and 3294 supercontigs. The best match of each SAS between all chromosomes and supercontigs was selected. Next, a threshold of 90% of coverage and 90% of identity was used to select the orthologue candidates. Further work is needed in order to extend the SAS and identify more orthologue candidates.

The EST sequences from the SUCEST database are essential for the Gene Expression and the Gene Annotation databases. However, they lack information about the promoters, and other regulatory elements, that are essential for the understanding of gene regulatory networks. A major sequencing effort has recently started in order to generate more information about regulatory elements of sugarcane genes. The Sugarcane Genome Sequencing Initiative ([http://bioenfapesp.org](http://bioenfapesp.org)) is focused in sequencing the sugarcane gene space using next generation sequencing tools. One approach is the use of massively parallel pyrosequencing in association with gene-enrichment methods. The CaneRegNet database is currently being prepared to integrate these sequences to the SUCEST database and the sorghum genome using GBrowser. Sequencing strategies are expected to include BAC sequencing, surveys of several cultivars using the shot-gun approach, ChIP-Seq (Chromatin Immunoprecipitation followed by sequencing), those targeting gene promoters and full length cDNA sequencing.

### 5) Functional Genomics

The vast amount of data contained in Gene Annotation, Gene Expression, Public Resources and Sequencing Projects databases must be organised in the context of the plant in order to provide new understanding of gene function and gene interaction, which are instrumental for the discovery of genes that regulate agronomic traits of interest. These genes can be used as molecular markers in breeding programs or to generate transgenic sugarcane plants.

Physiology studies and transgenic sugarcane plants will be used to test hypotheses regarding gene regulatory networks and for assigning function to the genes identified. The CaneRegNet database will store information on all plant samples, including agronomic traits such as growth...
rates, water use efficiency, photosynthesis parameters, and sugar and cell wall content of sugarcane genotypes. Information on the protocols, experiments, clones, vectors and primers as well as the results generated will be stored and visualised by a web interface and integrated into the Relational database with the other resources.

Discussion and future directions

An evolving integrated platform has been developed to integrate and store a large amount of data from diverse sources and experimental conditions. The SUCEST-FUN db provides the infrastructure for storage, retrieval and integration especially for deep sequencing genomics, DNA methylation filtration experiments, Molecular Markers, ChIP-Seq data, expression data, gene catalogues and information on sugarcane physiology and from the analysis of transgenic plants. The mediator approach will allow the running of parallel queries, do parallel loads into multiple SUCEST-FUN db instances, and provide unlimited data storage and management. The SUCEST-FUN db will be an important tool for scalable storage and interpretation of these data. New datasets will be available as soon as the accompanying papers are released.

The search and analysis tools developed in the project have allowed correlations to be made among gene expression experiments as well as among groups of experiments treating different conditions and treatments. The tools have also permitted the consolidation of the data with manually curated genes, gene catalogues and aggregated public resources such as GO and KEGG.

The extent of genetic and genomic information available on several species, such as barley, wheat, maize, rice, and sorghum, which belong to different tribes in the grass family, has enabled the most comprehensive comparative genomic studies in plants (Eckardt, 2008). The SUCEST-FUN db will be fundamental for the development of new tools and analysis of the sugarcane genome and functional genomic studies.

In the future, this platform will be composed of new algorithms and analysis tools, which are to be based on mathematical and statistical methodologies and draw on numerous biological resources. These resources will exploit the whole sugarcane genome sequence, the transcriptome and functional genomic data. This will allow the application of a Systems Biology approach to sugarcane in order to identify regulatory gene networks, discover new genes and develop improved ‘energy’ cultivars.

REFERENCES


LE RÉSEAU DE LA BASE DE DONNÉES SUCEST-FUN: LA CONCEPTION D’UNE CANNE ÉNERGIE

Par


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MOTS CLÉS: Canne à Sucre, Base de Données SUCEST-FUN, Bioinformatiques, Séquence Du Génome, Transcriptome, Régulation du Gène.

Résumé

LES CULTIVARS modernes de la canne à sucre sont des hybrides complexes résultant de croisements entre plusieurs espèces de Saccharum. Au cours des dernières décennies, des méthodes d’amélioration génétique traditionnelles ont été surtout employées dans différents pays pour développer des variétés à fort rendement en saccharose et résistantes aux ravageurs et aux maladies. Cependant, l’amélioration des variétés par ces méthodes, est limitée par la gamme restreinte de gènes appropriés. Ainsi, la génétique moléculaire est considérée comme un outil prometteur pour aider au processus d’amélioration variétale. Le projet SUCEST-FUN (http://sucest-fun.org) vise à associer des fonctions à des gènes de la canne à sucre en utilisant une variété d'outils, en particulier ceux permettant l'étude du transcriptome. Une analyse approfondie a été menée afin de caractériser, les génotypes de canne à sucre basés sur les phénotypes suivants: la teneur en saccharose, la biomasse et la réponse à la sécheresse. Grâce à l'analyse de différents cultivars, les gènes responsables pour la teneur en saccharose et la lignine, ainsi que pour une réponse à la sécheresse ont été identifiés. Actuellement, des outils sont en cours de développement pour déterminer les réseaux de signalisation et de régulation parmi les graminées, ainsi que pour le séquençage du génome de la canne à sucre, et pour identifier des promoteurs de la canne. Ces projets sont réalisés par l'intermédiaire du programme SUCEST-FUN (http://sucest-fun.org) et les bases de données GRASSIUS (http://grassius.org), avec le support du clonage des promoteurs de la canne à sucre, l'identification des éléments cis-régulatoires (ECR) à l'aide de la méthode ChIP (Chromatin Immunoprecipitation-sequencing), et la génération d’un catalogue SUCAST détaillé (Signal Transduction and Transcriptome Gene catalogue).
LA BASE DE DATOS DE LA RED REGULATORIA SUCEST-FUN:
DISEÑANDO UNA GRAMÍNEA ENERGÉTICA

Por

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PALABRAS CLAVE: Caña de Azúcar, Base de Datos SUCEST-FUN,
Bioinformática, Secuencia del Genomio, Transcriptomo, Regulación.

Resumen

Los cultivares de la caña de azúcar son híbridos complejos resultantes de las cruzas interespecíficas de *Saccharum*. Métodos convencionales de fitomejoramiento han sido extensivamente usados en diferentes países a lo largo de las pasadas décadas para desarrollar variedades con un rendimiento mayor de sacarosa y resistencia a plagas y enfermedades. Sin embargo, el fitomejoramiento convencional puede limitarse por una reducción en la poza de genes adecuados. Por tanto, la genética molecular es vista como una herramienta prometedora para apoyar el proceso de desarrollo de variedades mejoradas. El proyecto SUCEST-FUN (http://sucest-fun.org) tiene como objetivo asociar la función de genes de la caña de azúcar usando una gama de herramientas, en particular aquellas que permiten el estudio del transcriptomo de la caña de azúcar. Un análisis extenso ha sido conducido para caracterizar, fenotípicamente, genotipos de caña de azúcar con respecto de su contenido de sacarosa, biomasa y respuesta a la sequía. A través del análisis de diferentes cultivares, han sido identificados los genes asociados con el contenido de sacarosa, el rendimiento, la lignina y la respuesta a la sequía. Actualmente, se están desarrollando herramientas para determinar las redes de señalización y regulación en gramineas, y para secuenciar el genomio de la caña de azúcar, así como para identificar promotores de caña de azúcar. Esto ha sido implementado a través de las bases de datos SUCEST-FUN (http://sucest-fun.org) y GRASSIUS (http://grassius.org), la clonación de promotores de caña de azúcar, la identificación de elementos *cis* de regulación (CRE, por sus siglas en Inglés) usando la Inmunoprecipitación–Secuenciación de Cromatina (ChIP-Seq, por sus siglas en Inglés) y la generación de un catálogo exhaustivo de Señalización de Transducción y Transcripción (Catálogo SUCAST).
PROSPECTS OF CELLULOSIC ETHANOL FROM SUGARCANE BAGASSE

By

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KEYWORDS: Biomass, Biofuels, Cellulosic Ethanol, Cellulases, Enzymes.

Abstract

Agricultural residues such as grain straws and corn stover are abundant, readily available biomass feedstocks for the production of next generation biofuels, with collection and transport costs being a major component of their cost. Sugarcane bagasse is thus an especially attractive biomass feedstock in that it is an agricultural residue already present in large quantities at sugar and ethanol mills. The efficient conversion of bagasse lignocellulose to fermentable sugars is the major techno-economic challenge to the commercially viable production of ethanol from this feedstock. Bagasse is first pre-treated by a combination of high temperatures and pressures in the presence of chemicals, to facilitate subsequent enzymatic hydrolysis to break down the cellulose and hemicellulose to fermentable sugars. The sheer volume (an estimated 15–25 kg/t bagasse) and costs of the enzymes required for hydrolysis make the process economically unfeasible using current fermentation-based enzyme production technologies. The expression of enzymes in crop plants represents a promising approach to reduce the costs of enzyme production, and is an area in which Syngenta has strong intellectual property and advanced proprietary technologies. Syngenta’s corn amylase, currently undergoing regulatory approval in the United States, features a thermostable \(\alpha\)-amylase expressed in the grain for dry grind ethanol production applications, the first of a series of Syngenta traits designed for the biofuels industry. To enable the \textit{in planta} production of cell wall-degrading hydrolases for commercial next generation biofuels production requires an integrated approach within an overall engineering process model, incorporating upstream pre-treatment and downstream fermentation methodologies in addition to enzyme expression, extraction, storage and hydrolysis technologies. Progress in the development of this suite of technologies for the conversion of bagasse lignocellulose to fermentable sugars will be described.

Biofuels

Global production and use of plant-derived transport fuels tripled from 2000 to reach 76.5 billion litres in 2008 (Sims et al., 2008). The increase in biofuels is due to several factors, including increasing petroleum supply uncertainty and rapidly rising demand for transport fuels, primarily from emerging economies. Government policies have promoted biofuels, driven by energy security concerns and political support for rural economies. Global biofuels production is dominated by the US, Brazil, the European Union and China, all of whom have strong policies supporting biofuels.
Concerns over greenhouse gas emissions have also contributed to increasing interest in biofuels. Replacement of gasoline with ethanol is estimated to reduce greenhouse gas emissions by approximately 30% to 85% compared to gasoline, depending on whether corn or sugarcane feedstock is used (Fulton et al., 2004). Importantly, biofuels are unique in their general compatibility with our existing liquid transport fuel infrastructure, despite the potential for ethanol-mediated corrosion of existing pipelines.

The United States and Brazil produce 52% and 37% of 2008 global fuel ethanol production, respectively (http://www.ethanolrfa.org/industry/statistics/#E – accessed 2 Oct 2009). US ethanol production is primarily from corn starch converted to fermentable glucose by the addition of enzymes. Limitations on available acreage and price pressures will likely restrict US grain-based ethanol to an estimated 8% of gasoline consumption on an energy-equivalent basis, or about twice current production (Tyner, 2008). Sugarcane ethanol production in Brazil was approximately 24.5 billion litres in 2008, but is estimated to increase to 79.5 billion litres by 2022 (Goldemberg and Guardabassi, 2009), consistent with projected increases of 50–100% in global sugarcane tonnage in the coming decade (Kline et al., 2008). However, ethanol production from sugarcane will eventually also be limited by lack of suitable land and by competing demand by alternative uses, in this case sugar production.

New technologies are needed for biofuels to significantly contribute to the global energy matrix and to greenhouse gas emission reduction. Biofuels currently represent less than 3% of our transport fuel (Koonin, 2006). The enzymatic hydrolysis of biomass to sugars that are fermented to ethanol represents the most attractive technology for continued expansion of biofuels production. Advantages of this technology include a high carbohydrate recovery efficiency, potential for continuous improvement through biotechnology, and lower capital costs (Carroll and Somerville, 2009; Wyman et al., 2005).

Cellulosic ethanol

Cellulosic ethanol has the potential to supply a significant portion of our transport fuel needs, while reducing greenhouse gas emissions (Wang et al., 2007). An estimated 30% of total gasoline consumption could be provided by biofuels from agricultural crop residues alone (Kim and Dale, 2004; Koonin, 2006). Cellulosic ethanol technology research has accelerated as a result of increasing funding and investment, but significant interrelated techno-economic challenges remain.

High production costs make commercial cellulosic ethanol production unviable at present. These are estimated at between US$102-123 per barrel (Tyner, 2008), or more than US$0.66 per litre (Coyle, 2007). Capital expenses and operating (feedstock, processing and enzyme) costs combine to make cellulosic ethanol production expensive relative to first-generation ethanol. In addition, cost estimates are based on models and pilot-scale research due to the lack of operational commercial-scale cellulosic ethanol plants, increasing the investment risk profile (Galbe et al., 2007).

To overcome this hurdle, the US and other governments and companies are providing research funding and subsidies to give incentives for the development of next generation biofuels, including subsidies for biomass crop production, transport and storage.

Sugarcane bagasse

Plant biomass (lignocelluloses) is composed primarily of cellulose, hemicellulose and lignin linked by a complex web of covalent and hydrogen bonds. Cellulose primary structure consists of a linear homopolymeric chain of β1,4 linked cellobiose (glucose dimer) subunits. Primary chains are organised into higher level structures, finally comprising a 7–30 nm cellulose microfibril of hundreds of primary chains within a hemicellulose matrix, and coated with lignin (Zhang and Lynd, 2004). Importantly, cellulose exists mostly in crystalline form in plant cell walls, and is thus insoluble in water and commonly used solvents.
Hemicellulose is a heterogeneous branched polymer of pentose (C5) and hexose (C6) sugars whose composition varies according to species. In grasses, glucuronoxylans are the primary hemicelluloses, comprising a β1,4 linked xylose backbone and branching arabinose and glucuronic acid side chains. Grass hemicellulose also contains mixed (β1,3– and β1,4) linkage glucose polymers (β-glucans (Vogel, 2008). Hemicellulose acts as the filler between cellulose microfibrils and provides structural rigidity.

Lignin is a complex phenylpropanoid heteropolymeric network of coumaryl, coniferyl and sinapyl alcohols that acts as the glue linking and strengthening the polysaccharide components (Jorgensen et al., 2007). Unlike cellulose and hemicellulose, the complex structure and diversity of chemical bonds in lignin make enzymatic deconstruction difficult (Weng et al., 2008).

Sugarcane bagasse is an economically attractive biomass feedstock for cellulosic ethanol production, already present in substantial quantities at sugar and ethanol mills, and commonly burned to provide energy for the mill and, increasingly, for electricity cogeneration. The average composition of sugarcane bagasse (dry) is approximately 39% cellulose, 23% hemicellulose (with 89% of this being xylan), 24% lignin and 5% ash content (US Department of Energy, 2009). By comparison, corn stover and grain straw used for cellulosic ethanol production will incur collection and transport costs and will thus have a higher cost basis than sugarcane bagasse feedstock.

Pre-treatment

Biomass must be pre-treated to reduce the recalcitrance of lignocellulose to enzymatic hydrolysis. In untreated material, lignin and hemicellulose reduce enzymatic activity by steric hindrance, and crystalline cellulose slows cellulase action. In addition, lignin, ash and other components can irreversibly bind to and inactivate enzymes, or reduce their activity (Himmel et al., 2007).

Biomass recalcitrance can be reduced by chemical as well as physical pre-treatment methods. Reducing biomass particle size and increasing porosity can reduce recalcitrance by facilitating substrate access by hydrolytic enzymes, but is likely too energy-intensive to be cost-effective. Chemical pre-treatments also act to improve substrate access, by removing or altering deposition of hemicellulose and/or lignin, or by changing the cellulose characteristics such as crystallinity. Pre-treatment typically involves treatment with either acid or alkalis at high temperatures (100–200°C) and pressure. Acid-based pre-treatments act primarily by converting hemicelluloses to component pentose sugars, with reaction conditions being a trade-off between improvement of subsequent enzymatic hydrolysis, and loss of sugars and generation of inhibitors of downstream processes caused by increasing pre-treatment severity. Alkali pre-treatments remove lignin rather than hemicellulose, minimising inhibitor formation but requiring the use of hemicellulases and of microbial strains capable of mixed C5/C6 sugar fermentation.

Commercially viable pre-treatments minimise the costs associated with energy and chemical inputs, removal of inhibitors, water usage and waste disposal, while maximising the recovery of fermentable sugars (Galbe and Zacchi, 2007; Jorgensen et al., 2007). Pre-treatment typically represents about 18% of total production costs and also impacts the efficiency of downstream processes (Yang and Wyman, 2008). Most pre-treatment methodologies involve high capital expenses due to the materials and engineering designs required (Eggeman and Elander, 2005).

Enzymes

Cellulases and hemicellulases belong to the large glycosyl hydrolase (GH) family of enzymes. Cellulose hydrolysis requires at least three enzymes: an endo-glucanase, an exo-glucanase and a β-glucosidase. Endo-glucanases (EG) act by hydrolysing internal glucosidic bonds, freeing up ends that are attacked by exo-glucanases or cellobiohydrolases (CBH) that move progressively along the cellulose chain, cleaving cellobiose units. Cellobiohydrolases come in two forms, CBH1 and CBH2, that work from the reducing and non-reducing ends of the cellulose polymer,
respectively. Finally, β-glucosidases (BG) hydrolyse cellobiose to glucose to produce fermentable sugar and relieve product inhibition of CBH by cellobiose.

Enzyme cost reduction is a key issue in the commercialisation of cellulosic ethanol. On a mass basis, enzyme production costs are similar, yet it takes an estimated 40–100 times more enzyme to digest cellulose compared to starch (Merino and Cherry, 2007). Low activity requires high loadings of approximately 15–25 kg of hydrolytic enzymes per tonne of biomass (Houghton et al., 2006; Taylor et al., 2008). Long reaction times require large vessel sizes and hence high capital costs. Enzyme costs for corn dry grind ethanol production range from US$2.64–5.28 per m^3 (= 1000 litres) of ethanol produced (Houghton et al., 2006), compared to about US$79.25 per m^3 of cellulosic ethanol (Lynd et al., 2008), or at least 20–40 times more (Somerville, 2007). Enzymes thus comprise an estimated 20–40% of cellulosic ethanol production costs.

Expression of enzymes in crops

Efficient enzymatic hydrolysis of biomass substrates remains the major economic and technical challenge in the development of cellulosic ethanol (Himmel et al., 2007; Wyman, 2007). Enzyme cost reduction is critical to favourable cellulosic ethanol process economics; since enzyme loadings have been extensively optimised, improvements in enzyme activity and/or reduction in production costs are required. Cellulases can be improved by protein engineering to have higher specific activity, reduced allosteric inhibition, high temperature tolerance and altered pH optima. Expression of cellulases and hemicellulases in crop plants has the potential to significantly reduce production costs, by getting around the capital and operating costs associated with fermentation (Sainz, 2009; Sticklen, 2008; Taylor et al., 2008). In combination, the expression of multiple improved enzymes in crop plants would dramatically improve cellulosic ethanol process economics.

Plants can produce enzymes at much lower cost than fermentation methodologies, and can also provide additional benefits. Syngenta (www.syngenta.com) is currently seeking deregulation from the United States Department of Agriculture for the first crop-produced enzyme product, designed for corn grain ethanol production. Amylase is used in the conversion of starch to fermentable glucose in corn grain ethanol production. Syngenta corn event 3272 expresses an α-amylase gene with an improved temperature and pH profile, replacing commercial amylase enzymes produced by fermentation, with additional benefits that reduce production costs (Syngenta, 2009).

The environmental benefits of Syngenta Corn Amylase (Enogen™) include estimated reductions of 8% in processing water and 6–11% in greenhouse gas emissions (Urbanchuk et al., 2009). While actual benefits are likely to depend on plant configuration, adoption of transgenic corn amylase technology has the potential to significantly improve the efficiency and environmental footprint of the US corn ethanol industry.

The technology for crop-based expression of cellulases and hemicellulases has significantly progressed over the past 15 years. A potential problem with the expression of hydrolytic enzymes in plants is that of impaired structural integrity of plant cell walls and, consequently, on crop standability. Strategies to effectively address this problem have included the use of appropriate expression tools, such as suitable promoters and subcellular targeting of enzymes.

Work done at Syngenta in the mid-1990s provided the first example of the expression of active cellulases in plants. Two endoglucanases (EG) and a cellobiohydrolase (CBH) sourced from Thermonospora fusca (since renamed Thermobifida fusca) were expressed from constitutive and inducible promoters and targeted to either the cytoplasm, the vacuole by use of targeting sequence, or to the chloroplast using direct transformation of the organelle (Lebel et al., 2008).

Nuclear transformants of tobacco, corn and wheat were generated that exhibited chemically induced cellulase expression. The Lebel et al. (2008) patent thus demonstrates cellulase expression in plants, and highlights thermostable enzymes, subcellular targeting sequences and inducible promoters as among the tools available to do so.
The importance of subcellular targeting in the expression of cell wall hydrolysing enzymes in plants has been confirmed in numerous reports. Successful targeting of cellulases and hemicellulases has been reported to chloroplasts, vacuoles, peroxisomes, mitochondria, endoplasmic reticulum, apoplast and cytoplasm (Sainz, 2009 and references therein). More recently, EG and CBH1 expressed in corn seed were targeted to different subcellular compartments (Hood et al., 2007).

Activity of ER-targeted versions was high for both enzymes, but EG also had activity when targeted to the vacuole but not the apoplast, whereas the reverse was true for CBH1. These results suggest that expression optimisation through targeting will likely depend on enzyme type. In other experiments, the highest activity was observed in plants with dual targeting of a xylanase to both the chloroplast and the peroxisome, compared to either compartment alone, suggesting a multiple targeting strategy to maximise expression (Hyunjong et al., 2006). Additional research on targeting multiple enzymes to subcellular compartments would help identify potential limitations to this strategy, e.g. whether localisation in certain compartments can interfere with enzyme accumulation in others.

Hydrolytic enzymes active at physiological temperatures have the potential to negatively impact plant structural characteristics. To limit this potential damage, the strategy of using cellulases and hemicellulases with high temperature optima and low activity at physiological temperatures has also been validated. Most reported experiments on cellulase expression in plants have used endoglucanases, principally using thermostable enzymes such as the *A. cellulolyticus* E1 EG and derivatives. Expression of thermostable CBH have been reported in several plant species (Sainz, 2009 and references therein), an important result given the need for relatively large amounts of CBH activity in biomass conversion.

Besides reducing the risk of unintended effects on plant structure, the use of thermostable enzymes has other potential advantages, including improved enzyme extraction, activity and stability, and lower process flow viscosities (Taylor et al., 2008; Viikari et al., 2007). Stable *A. cellulolyticus* E1 EG activity was demonstrated in dried leaf material from tobacco and alfalfa (Dai et al., 2000; Teymouri et al., 2004; Ziegelhoffer et al., 1999), and in frozen crude extracts (Sticklen, 2006). Stability, extraction and storage are important considerations for the effective use of plant-expressed enzymes in processing.

High-level enzyme expression in an agricultural setting is the main challenge in delivering inexpensive, plant-produced cellulases and hemicellulases for cellulosic ethanol production. *A. cellulolyticus* EG has been expressed as high as 2% total soluble protein (TSP) in corn stover (Biswas et al., 2006; Mei et al., 2009), although an estimated 10% of TSP is needed for complete hydrolysis (Sticklen, 2008). In contrast, both EG and CBH1 constituted about 16–18% TSP in maize seed in the best expressing lines (Hood et al., 2007), or about 0.05% of dry grain weight. It is estimated that approximately 9 times this enzyme yield would be required to use the grain produced to process the corn stover from the same hectare (Sainz, 2009). Target yields for different plant-expressed hydrolytic enzymes will depend on various factors, including the type of pretreated feedstock and the activity, loading and optimal ratios of the enzymes needed for efficient biomass hydrolysis, together with consideration of any losses incurred during extraction and storage prior to use.

Significant levels of cellulase expression in corn leaves (7–10% of TSP) have been obtained in experiments conducted at Syngenta Biotechnology, Inc. (Warner et al., unpublished data). Importantly, the performance of the corn leaf-expressed exoglucanase on pre-treated sugarcane bagasse was roughly comparable to the activity of microbially produced enzyme when assayed in defined composition enzyme cocktails. Similar studies on cellulase expression in sugarcane are being conducted at the Queensland University of Technology (QUT) in the Syngenta Centre for Sugar Cane Biofuels Development, a unique public-private research collaboration between
Syngenta and QUT (Sainz and Dale, 2009). Preliminary experiments using the constructs shown to be functional in corn have generated events with cellulase activity, mirroring the results observed in corn (Sainz et al., unpublished data). Taken together, these results are important in demonstrating the viability of crop-expressed hydrolytic enzyme product concepts for cellulosic ethanol production from both corn stover and sugarcane bagasse.

**Conclusions**

Increasing global energy demand will drive the development of technologies for environmentally sustainable transport fuels. Cellulosic ethanol and other advanced biofuels can help to meet future energy needs with a more favourable environmental profile than first-generation biofuels (Woods et al., 2009). Given existing infrastructure, enzymatic hydrolysis represents the most attractive near-term approach for biomass to biofuels conversion, with ongoing improvements through biotechnology (Wyman et al., 2005). Process models identify conversion of lignocellulosic biomass into fermentable sugars as the key challenge in reducing cellulosic ethanol production costs (Lynd et al., 2008). Longer-term, biomass feedstock modification to improve yield and processing characteristics, the development of improved organisms for fermentation, and improved engineering designs will increase process efficiencies, reducing capital costs per litre of cellulosic ethanol produced, costs that are currently about three times higher than equivalent costs for a corn ethanol plant (Galbe et al., 2007).

Sugarcane bagasse is the most cost-effective feedstock for cellulosic ethanol production, but commercial viability will depend on being able to lower the cost and improve the effectiveness of cellulases, and to develop pre-treatment technologies compatible with an optimised, integrated process, especially downstream enzymatic hydrolysis and fermentation. In the future, success in improving the cost basis of cellulosic ethanol production will likely require increasingly integrated technical solutions drawing from diverse disciplines, including agronomy, plant breeding and microbiology, in addition to biotechnology, enzymology and engineering. Process modelling will be important in guiding research, by identifying the most promising areas for improvements and cost reductions in making cellulosic ethanol production economically viable. In addition, standardised life cycle analysis methodologies will need to be developed to account for environmental costs and benefits in effectively comparing different options towards meeting our future energy needs.

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PERSPECTIVES DE PRODUCTION DE L’ÉTHANOL CELLULOSIQUE À PARTIR DE LA BAGASSE DE LA CANNE À SUCRE

Par

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MOTS-CLÉS: Biomasse, Biocarburants, Éthanol Cellulosique, Cellulases, Enzymes.

Résumé
Les résidus agricoles comme la paille et les résidus du maïs sont abondants et facilement disponibles comme matières premières pour la production de la deuxième génération de biocarburants. Cependant, la collecte et le transport demeurent les composantes principales au coût. La bagasse de canne représente une matière première intéressante dans le sens que c’est un résidu disponible en grande quantité dans les sucreries et usines d’éthanol. La conversion efficiente de la bagasse ligno-cellulosique en sucres fermentables est un défi technico-économique majeur pour une production industrielle viable d’éthanol. La bagasse est d’abord prétraitée par une combinaison de haute température et de pression en présence de produits chimiques, afin de faciliter l’hydrolyse enzymatique subséquente pour la décomposition de la cellulose et de l’hemicellulose en sucres fermentables. Le volume conséquent (estimé à 15–25 kg/t bagasse) et le coût des enzymes nécessaires pour l’hydrolyse font que le processus n’est pas économiquement envisageable avec la présente technologie de fermentation enzymatique. L’expression des enzymes dans des plantes représente une approche prometteuse pour une réduction du coût de l’enzyme, et c’est dans ce domaine que Syngenta a une propriété intellectuelle solide et une technologie propriétaire avancée. L’amylase de maïs de Syngenta qui se caractérise par un α-amylase thermstable avec expression dans le grain pour le broyage à sec dans les applications de production d’éthanol, fait actuellement l’objet de la recherche d’approbation réglementaire aux États Unis. C’est le premier d’une série de caractères que Syngenta a l’intention de destiner à l’industrie des biocarburants. La production in planta des hydrolases pour dégrader la paroi cellulaire requiert une approche intégrée à l’intérieur du modèle de l’ensemble du processus d’ingénierie. Elle incorpore des méthodologies de fermentations de pré-traitements en amont et en aval en sus des technologies ayant trait à l’expression d’enzyme, d’extraction, de préservation et d’hydrolyse. Le progrès dans le développement de cette suite de technologies pour la conversion de la bagasse ligno-cellulosique en sucres fermentables est décrit.
PROSPECTOS PARA EL ETANOL CELULÓSICO A PARTIR DEL BAGAZO DE LA CAÑA DE AZÚCAR

Por

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PALABRAS CLAVE: Biomasa, Biocombustibles, Etanol Celulósico, Celulasas, Enzimas.

Resumen

RESIDUOS agrícolas tales como la paja derivada de cereales y el rastrojo del maíz son abundantes materias primas, las cuales se encuentran fácilmente disponibles para producir biocombustibles de siguiente generación; sin embargo, los costos de colecta y de transporte son grandes componentes en su costo. El bagazo de caña de azúcar es, por tanto, una materia prima especialmente atractiva puesto que se encuentra presente en grandes cantidades en molinos de azúcar y etanol. La conversión eficiente de la lignocelulosa del bagazo en azúcar fermentable es el mayor reto tecnológico y económico para una viable producción comercial del etanol a partir de tal materia prima. El bagazo cursa un pretratamiento con una combinación de altas temperaturas y presiones en presencia de reactivos químicos, a fin de facilitar subsecuentes hidrólisis enzimáticas, degradar la celulosa y hemicelulosa y convertirlas en azúcares fermentables. El volumen puro (estimado en 15-25 kg/tn de bagazo) y los costos de producción de los enzimos requeridos para la hidrólisis hacen económicamente inviable al proceso de usarse las actuales tecnologías de producción de enzima para la fermentación. La expresión de enzimas en cultivos vegetales representa un enfoque promisorio para reducir los costos de la producción de enzimas, y es una área en la que Syngenta posee un gran propiedad intelectual y avanzadas tecnologías propietarias. La amilasa de maíz de Syngenta, actualmente bajo aprobación regulatoria en los Estados Unidos, presenta características de una α-amilasa termoestable expresada en el grano para aplicaciones en la producción de etanol a partir del molido seco, siendo la primera de una serie de caracteres de Syngenta diseñados para la industria de biocombustibles. Para facilitar la producción in planta de hidrolasas degradantes de pared celular para la producción comercial de siguiente generación de biocombustibles, se requiere un enfoque integrado dentro de un modelo completo de ingeniería de procesos, incorporando pretratamientos en fases superiores del proceso y metodologías de fermentación en fases resultantes del proceso, adicionales a aquellas de expresión enzimática, extracción, almacenaje e hidrólisis. El avance en el desarrollo de esta serie tecnológica para la conversión de lignocelulosa del bagazo en azúcares fermentables será descrito.
GENETIC DIVERSITY OF *METARHIZIUM ANISOPLIAE* FROM SUGARCANE FIELDS IN TABASCO STATE, MEXICO

By

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KEYWORDS: *Aeneolamia postica*, *Saccharum* spp., Entomopathogenic Fungus, Biological Control, Molecular Characterisation.

Abstract

*Metarhizium anisopliae* (Metschn.) Sorokin (Moniliaceae: Moniliaceae) is an entomopathogenic fungus used as a biological control agent against the sugarcane froghopper *Aeneolamia postica* (Wlk.) (Hemiptera: Cercopidae), one of the main insect pests of sugarcane in Tabasco State, Mexico. Since 2005, multiple isolates of *M. anisopliae* have been applied by farmers in the crop areas; however, the current genetic diversity of the fungus population in the field is unknown. The aim of this study was to characterise isolates of *M. anisopliae* collected in sugarcane fields to better understand their genetic and virulence characteristics against *A. postica*. In particular, the impact of introduced isolates on the genetic diversity of native strains was determined. Sampling of mycosed insects was conducted in soils from the main sugarcane fields of Tabasco. Twenty isolates of *M. anisopliae* were obtained and a monosporic culture from each one was used for the characterisation studies. The isolates were characterised using both morphological characteristics and rDNA analysis. The genetic diversity of the fungus was analysed by means of RAPD molecular markers. One of the isolates was significantly similar to the isolate introduced by farmers. RAPD analysis revealed a homogeneous group among the native isolates collected in sugarcane fields in Tabasco. These results suggest a very low incidence of recombination between native and introduced isolates. The implications of the findings on the genetic diversity of *M. anisopliae* and the use of this pathogen for biological control products for *A. postica* are discussed in this paper.

Introduction

Sugarcane (*Saccharum* spp.) has given rise to an agro-industrial system in Mexico, which plays a significant role in its economic and social activity and is currently the most important agro-industry of the country (Bautista and González, 2005; Hernández-Rosas *et al.*, 2007). Seven hundred thousand ha distributed over 15 states are devoted to sugarcane cultivation and 58 sugar factories operate with an average yield of 76 tonnes/ha and 11% final product manufactured (Hernández-Rosas *et al.*, 2007). Mexico is one of the ten main producers of sugarcane in the world.
and, with a per capita consumption of 50 kg, it is the second highest sugar consumer. It is estimated that three million Mexicans depend on this economic activity, which also generates an important amount of foreign currency (Hernández-Rosas et al., 2007).

The production and quality of sugarcane is limited by the sugarcane froghopper *Aeneolamia postica* (Wlk.) (Hemiptera: Cercopidae), the most damaging insect pest present over extensive areas of the Gulf of Mexico and Pacific Ocean coastal plains (Bautista and González, 2005). This pest provokes reductions in sugarcane yield of up to 60% and is controlled by means of pesticides, which increases production costs as well as having a negative impact on the environment (Hernández-Rosas et al., 2007).

Due to the fact that the froghopper has become resistant to many insecticides, sugarcane producers of the State of Tabasco, Mexico, have searched for alternative control methods. One such alternative available is *Metarhizium anisopliae* (Metschn.) Sorokin (Moniliales: Moniliaceae), an entomopathogenic fungus that is widely used in biological control of insect pests (Guerrero et al., 1999; Hernández-Rosas et al., 2007).

Since 2005, farmers have introduced several isolates of *M. anisopliae* as part of an integrated pest management strategy in sugarcane fields of Tabasco (Bautista and Gonzalez, 2005). However, the persistence of these isolates in the sugarcane fields after their application and their impact on the native populations are not known.

The present study was conducted in order to generate knowledge related to these issues and to characterise the genetic diversity of the entomopathogenic fungus *M. anisopliae* isolates originating from the main sugarcane growing areas in the Rios region of Tabasco State, Mexico.

**Materials and methods**

**Study area**

The study was carried out in sugarcane fields found in the Rios region, municipality of Tenosique, Tabasco, Mexico. These fields supply the AZSUREMEX S.A. de C.V. sugar factory, which is located on the La Palma highway, Tenosique at 17° 25’ N, 91° 24’ W, and 60 m altitude. The area cultivated with sugarcane in the Rios region is 4209.83 ha.

**Sampling**

Two types of sampling were undertaken to collect *M. anisopliae* from the sugarcane fields. Samples were taken from either the soil or from mycosed insects. As applications of *M. anisopliae* have been made since 2005, samples were taken from fields with and without fungus application history belonging to 33 farmers, representing 5.06% of the total number of sugarcane producers and 4.7% of the total sugarcane cultivated area in the Rios region. On average, each farmer possessed 6 ha of sugarcane.

The farmer’s sugarcane fields were sampled. A five point sample was carried out, one in each corner of the field and another in the centre, taking the sample at a depth of 10 cm within the rhizosphere. The technique suggested by Almeida et al. (1997) was followed for the collection of soil samples, which consisted in taking five 0.5 kg soil sub-samples from the upper 10 cm of soil, close to the crop’s rhizosphere and with 5.0 cm between each sample. The soil samples were placed in plastic bags and transported to the laboratory in dry ice boxes at 4°C. The samples were collected between September and December of 2007 and 2008.

**Isolation**

In order to isolate *M. anisopliae* from the soil, *Galleria mellonella* L. (Lepidoptera: Pyralidae) larvae were used (Vanninen, 1997). The soil samples were sieved through a 2.0 mm metallic mesh sieve and 300 g of soil was moistened and placed in a 500 mL plastic tumbler. Subsequently, five larvae were introduced into each tumbler, sealed with sellotape and incubated for seven days at 25°C (Bedding and Akurst, 1975; Doberski and Tribe, 1980). After incubation, the larvae were examined.
The diseased insects were separated from the soil and disinfected in 5% sodium hypochlorite (NaOCl) for one min followed by 70% alcohol for five seconds. They were then rinsed three times with sterile distilled water, and excess water removed using tissue paper (Douglas et al., 2008).

The larvae were then placed in a 100 mm × 15 mm Petri dish with a double layer of damp filter paper and subjected to the aforementioned incubation conditions to favour fungus development (Hatting et al., 1999).

Mycosed insects were observed with a stereoscopic microscope to detect the body areas with highest sporulation. In order to isolate *M. anisopliae* from field-collected samples of mycosed insects of *A. postica*, the procedures mentioned above for *Galleria mellonella* mycosed larvae were followed.

The isolated fungi were identified by their reproductive structures using the keys elaborated by Tulloch (1976) and Harper and Haung (1986).

The isolates obtained from the sugarcane fields in the Rios region of Tabasco are presented in Table 1. Isolate 9 was the reference isolate of *M. anisopliae* and was obtained from the ‘Tiemelonlà Nich Klum’ laboratory in Palenque, Chiapas, Mexico; this isolate was applied on Mr Barrada’s land in 2005. The first 10 isolates (1–10) were analysed by the Random Amplified Polymorphic DNA (RAPD) technique.

Subsequently, all the isolates were analysed by means of rDNA analysis, restriction analysis of amplified products and digestion with the *Hae* II enzyme.

**Table 1**—Isolates of entomopathogenic fungi analysed in this study.

<table>
<thead>
<tr>
<th>No.</th>
<th>Code</th>
<th>Species</th>
<th>Source of isolate</th>
<th>Year collected</th>
<th>GPS Coordinates</th>
<th>UTM Units</th>
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<td>MM0801</td>
<td><em>Aeneolamia</em> spp.</td>
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<td>4</td>
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<td>2008</td>
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<td>Unknown</td>
<td>CNRCB</td>
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¹*Metarhizium anisopliae* isolate provided by the ‘Tiemelonlà Nich Klum’ laboratory located in Palenque, Chiapas, Mexico.

²Centro Nacional de Referencia en Control Biológico, Tecomán, Colima, México.
Genomic DNA

Monosporic cultures were used to obtain the inoculum, which was grown on potato dextrose agar (PDA) (Hernández-Rosas, 2002). The inoculum was incubated and agitated for three days at 27°C in potato dextrose broth and the mycelium was recovered on a sterile filter paper using a funnel and a vacuum pump.

The mycelium was then placed in a sterilised, cooled mortar and ground with (L) N₂ to a fine dust, which was transferred to a sterile 1.5 mL tube before application. The protocol described by Gómez-Leyva et al. (2008) for the extraction of genomic DNA from M. anisopliae was followed.

The samples were stored at 4°C until required. The DNA was analysed on 0.8% of sodium borate agarose gel, stained with ethidium bromide and visualised under ultraviolet light (UV).

RAPD analysis

The RAPD technique described by Williams et al. (1990) was utilised to generate molecular patterns. The OPB07 (GGTGACGCAG) and OPB09 (TGGGGGACTC) Series B Operon primers were used (Operon Technologies Inc., Alameda, EUA) (Cobb and Clarkson, 1994; Guerrero, et al., 2000; Kendall and Rygiewicz, 2005). The reaction mixture consisted of a mixture of 0.2 mM dNTPs, 10 μM of primer, 2.5 U of Ta q polymerase DNA (Promega, Madison, Wisconsin, USA) and 100 ng of DNA.

The Polymerase Chain Reaction (PCR) amplifications were carried out in a MJ Research thermocycler programmed as follows: 2 min at 94°C followed by 40 cycles of 1 min at 94°C, 1 min at 36°C and 90 seconds at 72°C; 7 min at 72°C and 4°C until removed. The amplified fragments were separated by horizontal gel electrophoresis in 1.2% agarose (Ultrapure, Gibco BRL, Gaithersburg, Maryland, US). The gels were stained with ethidium bromide and photographed on a UV Cole Palmer 97500 transilluminator.

Amplified ribosomal DNA restriction analysis (ARDRA)

The Internal Transcribed Spacer (ITS) region of the rDNA from each sample was amplified using the following reaction mixture: buffer 1X pH 8.5, primers ITS1 and ITS4 (White et al., 1990) at 20 pmol each, 0.2 mM dNTPs, 2.0 mM of MgCl₂, 2.5 U of Taq polymerase DNA and 100 pmol of DNA under the following thermocycler conditions: 3 min at 94°C followed by 30 cycles of: 1 min at 94°C, 1 min at 55°C, 1 min at 72°C with a final extension of 7 min at 72°C. The amplified products were digested with the Hae II restriction enzyme and separated in a 1.6% agarose gel.

Estimation of genetic diversity

M. anisopliae genetic diversity was analysed through polymorphism expressed by the primers. A 0, 1 matrix, referring to the absence or presence of bands in each M. anisopliae isolate, was recorded from the RAPD amplifications and ARDRA results.

The variations in band intensity were not assigned as differences. The matrix was prepared using the Neighbor-Join coefficient. The dendrograms were made by means of a UPGMA analysis with the NTSYS 2.0 (Numerical Taxonomy and Multivariate Analysis System) program (Rohlf, 1993).

Results

RAPD analysis

The RAPD amplification of DNA of M. anisopliae isolates 1 to 10 with OPB09 is presented in Figure 1. Genetic variation was observed among the isolates, with polymorphic bands ranging between 250 bp and 1000 bp. Bands of 250, 400, 500, 700 and 800 bp were amplified for isolates 1 and 4; 1, 2, 5, 6, 8, 9, 13 and 10 respectively. The isolates 1 and 8 (from Field of Mr Miguel Mujica and Field Mr Gustavo Barradas belonging to A. postica) and isolates 2, 3, 4, 5, 6, 7 and 10 all collected from the technique insect-tramp with G. mellonella. The isolate 9 was the reference isolate provided by the ‘Tiemelonlà Nich Klum’ laboratory located in Palenque, Chiapas, Mexico.
ARDRA analysis

The results of the rDNA amplification and restriction analysis of the amplified products of the isolates studied are presented in Figure 2. The approximately 600 bp fragment was amplified with ITS1/ITS4 primers (Figure 2A) in all isolates with the exception of isolate 12 which produced a 850 bp band.

Digestion using the Hae II enzyme (Figure 2B) resulted in the generation of 200 to 400 bp. Some bands did not follow the general pattern, possibly a result of incomplete digestions. These bands were not analysed in this study.

In the dendrogram generated from the restriction analysis of the isolates (Figure 3), three principal groups were observed; the first group consisted of isolates 1, 2, 3, 4, 5 and 6. The second group consisted of isolates 7, 8, 9, 10 and 11.

The third main group was made up of isolates 14 and 16, followed by four isolates; 70 and 74 provided by the Centro Nacional de Referencia en Control Biológico (CNRCB) and isolates 12 and 13.

Discussion

As expected, the results indicated genetically similar patterns between the reference isolate (number 9) applied three years ago in the cane fields at Barradas and isolate 1 that was collected in the same locality. There is a high probability that this isolate originated from the reference isolate, demonstrating that M. anisopliae is capable of persisting in the environment with relatively low variation. These results are consistent with those reported by Milner et al. (2003) where it was found that M. anisopliae conidia survived 3.5 years post application in fields in Australia.

Genetically similar patterns were also observed between the reference isolate 9 and isolates 5, 6, 10 and 13 collected from fields where the former had not been applied. Bidochka et al. (1994) mentioned that *M. anisopliae* could be a cryptic species; in a genetic diversity study in two regions where this fungus had already been applied, the authors found a very low degree of recombination.

It seems that the host insect exerts the predominant influence on entomopathogenic fungi population genetics (Bidochka et al., 1994). Douglas et al. (2008) mention that ecological zones play an important role in the study of *M. anisopliae* genetic diversity.

In this study, the habitat was purely sugarcane which possibly provides another reason for the low genetic variability found in *M. anisopliae*. It has also been found that selection pressure exerted by biotic and abiotic factors affect the pathogenic capacity of this entomopathogen (Zimmerman, 2007).

According to Hajeck and St. Leger (1994) who tried to explain the high intraspecific genetic variability observed between *M. anisopliae* isolates, many of these isolates are included in a few
geographically distributed genotype classes and whose persistence over time and space suggests that in many situations they originate from a clonal population structure.

The results of this study also demonstrate that isolates 1–2, 8–9, 14–16 were genetically similar and isolates 4, 5, 6, 3, 7, 8 and 9 displayed the least genetic similarity. This demonstrated the natural occurrence of genetic variation in the *M. anisopliae* fungus.

The question that arises from this information is whether this genetic variability affects the virulence of the entomopathogen towards *A. postica*. According to Fegan et al. (1993) who carried out a RAPD analysis on *M. anisopliae* var. *anisopliae*, the high degree of observed genetic diversity would be related to both its geographical origins and groups of pathogenicity.

Fig. 3—Dendrogram based in the amplified ribosomal DNA restriction analysis (ARDRA) in different strains of entomopathogens.

Hajek and St. Leger (1994) point out that geographic isolation and limited dispersion capacity of *M. anisopliae* spores could be important in the evolution of different genotypes.

These authors also mentioned that the intra-specific variability of fungi has been characterised by differences regarding pathogenicity.

Documented cases of variability in host susceptibility to the pathogen showed the potential occurrence of co-evolution between the host insect and the pathogenic fungus.

Other authors have discovered that the pathogenicity of *M. anisopliae* is genetically distinct, in accordance with different soil types present in the sugarcane zones (Milner, 1992) and that this fungus develops different adaptations in function of the prevailing soil type and/or rhizosphere where it is present (Meyling and Eilenberg, 2007).

Future research will aim to understand the relationship between genetic diversity of *M. anisopliae* isolates collected in this study and their pathogenicity on *A. postica*. 
Conclusions

The following conclusions can be made from the molecular studies of *M. anisopliae* carried out in this research:

1) There exists a high probability that at least one of the isolates originated genetically from the reference isolate, thus implying that *M. anisopliae* is capable of persisting in sugarcane fields three years after being applied.

2) Observed variations in genomic DNA of *M. anisopliae* suggest the presence of a high natural genetic diversity among the studied isolates.

Acknowledgements

We thank *Fondos Mixtos* CONACYT-Tabasco State Government for financial support of this study. We are especially grateful to the sugarcane producers of the Rios region in the municipality of Tenosique, Tabasco for facilitating access and studies within their sugarcane fields.

REFERENCES


DIVERSITÉ GENÉTIQUE DE *METARHIZIUM ANISOPLIAE* PROVENANT DES CHAMPS DE CANNE À SUCRE DE L’ÉTAT DE TABASCO AU MEXIQUE

Par

ARELY BAUTISTA GALVEZ\textsuperscript{1,2}, JUAN F. BARRERA\textsuperscript{2}, EMETERIO PAYRÓ DE LA CRUZ\textsuperscript{3}, SERGIO SALGADO GARCÍA\textsuperscript{4}, JAIME GÓMEZ RUIZ\textsuperscript{2} et JUAN FLORENCIO GÓMEZ LEYVA\textsuperscript{5}

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MOTS-CLÉS: *Aeneolamia postica*, *Saccharum* spp., Champignon Entomopathogène, Lutte Biologique, Caractérisation Moléculaire

Résumé

Le *METARHIZIUM anisopliae* (Metschn.) Sorokin (Moniliiales: Moniliaceae), un champignon entomopathogène, est utilisé dans la lutte biologique contre la cicadelle écumuse de la canne à sucre *Aeneolamia postica* (Wlk.) (Hemiptera: Cercopidae), un des principaux ravageurs de la canne à sucre de l’État de Tabasco au Mexique. Depuis 2005, plusieurs isolats de *M. anisopliae* ont été appliqués par les fermiers dans les champs sous culture ; toutefois, la diversité génétique de la population du champignon demeure inconnue. L’objectif de cette étude consistait à caractériser les isolats de *M. anisopliae* collectés dans les champs de canne à sucre afin de mieux comprendre leur diversité et leur virulence contre *A. postica*. En particulier, l’impact des isolats introduits sur la diversité génétique des isolats indigènes a été déterminé. Un échantillonnage des insectes mycosés a été effectué dans les principaux sols de Tabasco. Vingt-deux isolats de *M. anisopliae* ont été obtenus et une culture monospore de chaque isolat a été utilisée pour les caractérisations morphologiques et les analyses d’ADN ribosomique. La diversité génétique a été analysée grâce aux marqueurs moléculaires RAPD. Un des isolats était significativement similaire à l’isolat introduit par les fermiers. L’analyse par RAPD a démontré que les isolats indigènes formaient un groupe homogène. Les résultats suggèrent un faible taux de recombinaison entre les isolats indigènes et ceux introduits. Les implications de ces résultats sur la diversité génétique de *M. anisopliae* et l’utilisation du pathogène pour la lutte biologique contre *A. postica* sont discutées dans cet article.
DIVERSIDAD GENÉTICA DE *METARHIZIUM ANISOPLIAE* EN CAMPOS DE CAÑA DE AZÚCAR EN EL ESTADO DE TABASCO, MÉXICO

Por

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PALABRAS CLAVE: *Aeneolamia postica*, *Saccharum* spp., Hongo Entomopatogénico, Control Biológico, Caracterización Molecular.

Resumen

*METARHIZIUM anisopliae* (Metschn.) Sorokin (Moniliáceas: Moniliaceae) es un hongo entomopatogénico usado como un control biológico en contra del insecto de la caña de azúcar *Aeneolamia postica* (Wlk.) (Hemiptera: Cercopidae), uno de las mayores plagas de la caña de azúcar en el Estado de Tabasco, México. Desde 2005, múltiples aislados de *M. anisopliae* han sido aplicados por agricultores en las áreas de cultivo; sin embargo, se desconoce la diversidad genética actual de la población fungal en el campo. El objetivo de este estudio fue caracterizar aislados de *M. anisopliae* colectados en campos de caña de azúcar para comprender mejor sus características genéticas y de virulencia contra *A. postica*. En particular, para determinar el impacto de aislados introducidos en cepas nativas. El muestreo de insectos con micosis fue conducido en suelos de los principales campos de caña de azúcar de Tabasco. Veinte aislados de *M. anisopliae* fueron obtenidos y un cultivo monospórico de cada uno fue usado para estudios de caracterización. Los aislados fueron caracterizados usando características morfológicas y de análisis de rADN. La diversidad genética del hongo fue analizada por medio de marcadores moleculares RAPD. Uno de los aislados fue significativamente similar al aislado introducido por los granjeros. El análisis RAPD reveló un grupo homogéneo entre los aislados nativos colectados en campos de caña de azúcar en Tabasco. Estos resultados sugieren una muy baja incidencia de recombinación entre aislados nativos e introducidos. En este artículo se discuten las implicaciones de los descubrimientos sobre la diversidad genética de *M. anisopliae* y el uso de este patógeno para productos de control biológico para *A. postica*.
MOLECULAR CHARACTERISATION AND APPLICATION OF BEAUVIERA BASSIANA (BALSAMO) VUILLEMIN IN THE BIOLOGICAL CONTROL AGAINST DIATRAEA SACCHARALIS (FABRICIUS)

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KEYWORDS: Diatraea saccharalis, Biological Control, Beauveria Bassiana Molecular Characterisation, Inter-Microsatellite, Sugarcane.

Abstract
MASSIVE application of the entomopathogen Beauveria bassiana in sugarcane fields is important both from an agronomic and ecological perspective. This has attracted interest for the development of reliable tools for the identification of the various species in use. The present work had as objectives the molecular characterisation of B. bassiana by inter-microsatellite (ISSRs) markers and the evaluation of the application of the hyphomycete in the biological control of Diatraea saccharalis (Fabricius). Genomic DNA was extracted from lyophilised mycelia. The amplified products were analysed with 100 ISSR primers. A high level of polymorphism (near 80%) was found among eleven isolates using fourteen ISSR primers selected. Seven different isolates showed exclusive bands and ISSR primer 873 distinguished all of them. The application of B. bassiana in the field was able to diminish live larvae of D. saccharalis by 43.7%, therefore demonstrating their potential as a biological control agent for sugarcane borer.

Introduction
Diatraea saccharalis (Fabricius) is the main pest of sugarcane in Cuba and it causes serious losses and damage to plantations. In order to reduce the population levels of the borer, the entomopathogenic fungus Beauveria bassiana (Bals.) Vuill. is used.

Natural occurrence of the fungus in Cuba was reported in larvae and pupae of D. saccharalis by Estrada et al. (2004). The pathogenicity of different isolates of the fungus was also determined in larvae of this Lepidopteran by Estrada et al. (1995).

There are several reports on the molecular characterisation of B. bassiana with the objective to study their genetic structure (McGuirre et al. 2005) and on the monitoring of the application of the fungus in the field (Wang et al. 2003).

The objective of the present work was to conduct a molecular characterisation of B. bassiana by intermicrosatellites, Inter Simple Sequence Repeats (ISSRs) and to determine the efficacy of application of the fungus in the biological control against D. saccharalis. The variability and the phylogenetic relationships between the eleven isolates of B. bassiana were analysed using ISSR markers as described by Estrada et al. 2007.

Materials and methods
Molecular characterisation of isolates of B. bassiana by ISSRs
Fungal isolates
Eleven isolates of B. bassiana from different geographic and entomological origins were used (Table 1). The isolates were grown in static liquid medium as described by Adamek (1965) and incubated at 25°C for four days. The fresh mycelia were harvested and lyophilised for 24 h.
Table 1—*Beauveria bassiana* isolates used in this study.

<table>
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**Genomic DNA extraction**

The lyophilised mycelia were used for genomic DNA extraction. The extraction was carried out using a small-scale DNA isolation method using Dneasy Plant Mini Kit, from Qiagen.

**Primers used in the PCRs test**

One hundred primers based on dinucleotide, tetracinucleotide or pentanucleotide repeats were used. These oligonucleotides were obtained from the University of British Columbia (UBC primer set 100/9). A total of fourteen oligonucleotides were selected based on the number and consistency of the amplified fragments.

**PCR and analysis of the amplified profiles**

Each amplification reaction (final volume of 20 µL) consisted of 1 µL of total genomic DNA (10 ng/µL), 1 µL of the corresponding primer (5 µM), 10 µL of Taq-PCR master mix (Qiagen) and 8 µL of ultra pure distilled water. DNA amplifications were performed in a PTC-100 Thermocycler with an initial step of 5 min at 94°C, followed by 45 cycles of 30 s at 94°C, 45s at 52°C and 2 min at 72°C with a final 6 min extension at 72°C.

The amplification reactions were stored at 4°C until resolved by electrophoresis. Samples of 20 µL PCR products were analysed on 1.5% agarose gels after running at 90 V for 2 h and staining with ethidium bromide.

ISSR markers behave as dominant markers. They were scored as presence (1) or absence (0) of homologous bands (bands with the same size) for all the isolates. Dendrograms were constructed by UPGMA (unweighted pair-group method, arithmetic average).

The cluster analysis was performed using different coefficients—the simple matching coefficient (SM), the DICE coefficient and the Jaccard coefficient (J) and using the NTSYS-pc version 1.6 package.

**Evaluation of the application of *B. bassiana* in field trials**

A randomised block design was used which consisted of eight plots of 96 m² each with 120 stools of a three-months old first ratoon crop of variety CB4452.

The plots were in parallel and separated by a distance of 200 m. To assure a homogeneous population of the pest, all the stools of the plots were infested artificially with egg batches of *D. saccharalis* ‘in black head’ stage (non developed embryos).

The infestation was carried out with 960 egg batches and the average number of eggs/batch was 26.71. Before the application of *B. bassiana*, the percentage of larvae hatching was calculated and it was 76.78%. *B. bassiana*-isolate 3 (MG1) was applied at a rate of 10¹² conidial/ha in the form of an aqueous suspension at a concentration of 6 × 10⁹ conidial/g.

It was applied in four experimental plots by means of a hand-operated knapsack sprayer. The control plots were treated with water.
Samplings were carried out at day 7, 15, 30, 45, 60 and 101 after the application of the fungus. In each sampling, four stools/plot were selected at random which were cut and analysed in the laboratory.

The number of affected stalks and internodes, the presence of live larvae of D. saccharalis, and presence of other natural enemies of the pest were recorded.

Considering the development cycle of the pest, at 30 days of sampling, the percentage of efficacy of the application of B. bassiana was determined by means of the Abbott formula (CIBA-GEIGY, 1981), which is used when the infestation of the pest is homogeneous before the application of the treatments:

\[
\text{% efficacy} = \frac{(C_d - T_d) \cdot 100}{C_d}
\]

where:

- \(C_d\): number of live individuals in the control plots after the treatment.
- \(T_d\): number of live individuals in the treated plots after the treatment.

A simple classification variance analysis was carried out and the means were compared by means of Newman Keuls's test (\(p < 0.05\)) (STATITCF, 1988).

**Results and discussion**

**Molecular characterisation of isolates of B. bassiana using ISSRs**

**ISSR amplification**

The sequences of these 14 primers used seem to indicate that the microsatellites that are more frequent in B. bassiana contain the repeated dinucleotides (AG)\(_n\), (AC)\(_n\) and (GT)\(_n\) (Table 2).

<table>
<thead>
<tr>
<th>Primer</th>
<th>Sequence</th>
<th>Primer</th>
<th>Sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>808</td>
<td>(AG)(_n)C</td>
<td>846</td>
<td>(CA)(_n)TR</td>
</tr>
<tr>
<td>809</td>
<td>(AG)(_n)G</td>
<td>849</td>
<td>(GT)(_n)YA</td>
</tr>
<tr>
<td>810</td>
<td>(GA)(_n)T</td>
<td>850</td>
<td>(GT)(_n)YC</td>
</tr>
<tr>
<td>818</td>
<td>(GA)(_n)C</td>
<td>873</td>
<td>(GACA)(_n)</td>
</tr>
<tr>
<td>821</td>
<td>(GT)(_n)A</td>
<td>885</td>
<td>BHB(GA)(_n)</td>
</tr>
<tr>
<td>828</td>
<td>(TG)(_n)A</td>
<td>889</td>
<td>DBD (AC)(_n)</td>
</tr>
<tr>
<td>842</td>
<td>(GA)(_n)YG</td>
<td>891</td>
<td>HVH(GT)(_n)</td>
</tr>
</tbody>
</table>

The 14 ISSR primers used for the PCR amplifications of DNA from the 11 isolates of B. bassiana were selected from the primers from the set 100/9 UBC, and gave reproducible amplification products (Figure 1).

The total number of bands (TNB), number of polymorphic bands (NPB), percentage of polymorphic bands (P\%), number of different genotypes (NG), resolving power (Rp) (Prevost and Wilkinson, 1999) and number of exclusive bands (NEB) obtained with each primer are shown in Table 3.

The total number of amplified products was 172 with an average of 12.28 bands/primer, ranging from 300 to 3000 bp, with 135 (78.49%) polymorphic DNA fragments.

The maximum number of amplified products was 18 (primers 809 and 810) and the minimum was 6 (primer 818) (Table 3).
Seven different isolates (five from Cuba, one from Bulgaria and one from USA), showed a total of 11 exclusive bands that could be transformed in Sequence Tagged Site (STS) markers.

Fig. 1—ISSR amplification products obtained from eleven isolates studied with ISSR primer 846 (A) and ISSR primer 889 (B).

Lanes/strain
1- strain MG1
2- strain 252
3- strain 18
12- repetition of strain 18
4- strain India
5- strain Bórer
6- strain Quivicán
7- strain PCC
8- strain 93
9- strain 60
10- strain CC
11- strain 156
M- molecular wt marker

Table 3—The total number of bands (TNB), number of polymorphic bands (NPB), percentage of polymorphic bands (P%), number of different genotypes or isolates identified (NG), resolving power (Rp) and number of exclusive bands (NEB) obtained each ISSR primer.

<table>
<thead>
<tr>
<th>Primer</th>
<th>TNB</th>
<th>NPB</th>
<th>P%</th>
<th>NG</th>
<th>Rp</th>
<th>NEB</th>
</tr>
</thead>
<tbody>
<tr>
<td>808</td>
<td>15</td>
<td>12</td>
<td>80</td>
<td>8</td>
<td>6.3</td>
<td>1</td>
</tr>
<tr>
<td>809</td>
<td>18</td>
<td>15</td>
<td>83.4</td>
<td>8</td>
<td>7.9</td>
<td>0</td>
</tr>
<tr>
<td>810</td>
<td>18</td>
<td>16</td>
<td>88.9</td>
<td>7</td>
<td>6.6</td>
<td>3</td>
</tr>
<tr>
<td>818</td>
<td>6</td>
<td>4</td>
<td>66.7</td>
<td>4</td>
<td>2.0</td>
<td>0</td>
</tr>
<tr>
<td>821</td>
<td>11</td>
<td>9</td>
<td>81.8</td>
<td>7</td>
<td>4.4</td>
<td>1</td>
</tr>
<tr>
<td>828</td>
<td>11</td>
<td>8</td>
<td>72.7</td>
<td>6</td>
<td>4.2</td>
<td>1</td>
</tr>
<tr>
<td>842</td>
<td>14</td>
<td>8</td>
<td>67.2</td>
<td>10</td>
<td>3.4</td>
<td>0</td>
</tr>
<tr>
<td>846</td>
<td>10</td>
<td>4</td>
<td>40.0</td>
<td>6</td>
<td>1.4</td>
<td>1</td>
</tr>
<tr>
<td>849</td>
<td>14</td>
<td>13</td>
<td>92.8</td>
<td>10</td>
<td>5.6</td>
<td>2</td>
</tr>
<tr>
<td>873</td>
<td>11</td>
<td>11</td>
<td>100</td>
<td>11</td>
<td>6.2</td>
<td>1</td>
</tr>
<tr>
<td>885</td>
<td>10</td>
<td>10</td>
<td>100</td>
<td>6</td>
<td>6.6</td>
<td>0</td>
</tr>
<tr>
<td>888</td>
<td>16</td>
<td>16</td>
<td>100</td>
<td>7</td>
<td>8.9</td>
<td>1</td>
</tr>
<tr>
<td>889</td>
<td>11</td>
<td>7</td>
<td>63.6</td>
<td>4</td>
<td>4.7</td>
<td>0</td>
</tr>
<tr>
<td>891</td>
<td>7</td>
<td>2</td>
<td>28.6</td>
<td>3</td>
<td>1.1</td>
<td>0</td>
</tr>
</tbody>
</table>
ISSR is easy to employ and highly reproducible. In this study, nearly 80% of the bands generated, using ISSR, were polymorphic. This shows the high level of genetic variation that exists between the different isolates.

These fungi display parasexual reproduction, which normally confers high genetic variability. In the same way, the ISSR markers proved to be an efficient marker system because of their capacity to reveal several informative bands in a single amplification (a mean of 9.6 bands/primer). Furthermore, it was possible to identify all the isolates with a single primer (873) (Figure 2).

The dendrograms obtained using the SM, DICE and J coefficients showed similar structure with the same clusters. The dendrograms generated have two distinct clusters (Figure 3). Cluster A contained the isolates from the Caribbean region and B had the isolates from other geographical locations.

The bootstrap values for the Cluster A and B were very high, 97% and 100%, respectively. The different isolates of cluster A exhibited nearly 75% similarity. Sub-cluster A1 contained just one isolate, MG1 from Cuba. This isolate is clearly different from the rest of the Caribbean isolates.
group consisting of isolates, which are to the right of the fork occurred.

This information is valuable because this isolate shows higher virulence than any of the other isolates used in Cuba. Also, it has been used in the sugarcane plantations in Cuba for biological control of the larval populations of *D. saccharalis*.

A specific diagnostic band for this isolate was obtained, and in future it could be possible to obtain a specific molecular marker for this isolate. The other Caribbean isolates exhibited a similarity greater than 82%, and are grouped in sub-cluster A2. It also had a high bootstrap value (100%).

The isolates from regions other than the Caribbean are in cluster B, and displayed more than 80% similarity. Between the two clusters, the similarity exhibited is less than 50%. This is a low value of homology, and showed the high genetic variability present between the isolates from the Caribbean region and the rest of the isolates.

The worldwide distribution of the *B. bassiana* isolates analysed using AFLPs was found to be very dissimilar (Uma et al., 2006). In another study involving 50 *B. bassiana* isolates of worldwide distribution, a very close similarity (80%) in AFLP fingerprints was reported by De Muro et al. (2003). The differences in the two studies could be explained by the fact that the different markers used detected polymorphisms in different regions of the genome.

**Application of *B. bassiana* isolate 3 in field trials**

Table 4 shows the results of the larval populations of *D. saccharalis*, the damage originated in the treated and untreated plots with the isolate 3 of *B. bassiana*. A significant difference among the evaluated treatments is observed in all the samplings carried out. The number of live larvae in the plots where the hyphomycete was applied was significantly inferior to the number of live larvae in the untreated plots.

Similarly the number of bored internodes was significantly lower in the treated plots. There was also a correlation between the presence of live larvae and the number of bored internodes showing that the fungus reduces the number of *D. saccharalis* larvae and consequently reduces damages caused to sugarcane fields.

<table>
<thead>
<tr>
<th>Samplings</th>
<th>Number of live larvae (mean)</th>
<th>Number of bored internodes (mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days</td>
<td>Plots treated</td>
<td>Plots control</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>1.75 (a)</td>
<td>2.50 (b)</td>
</tr>
<tr>
<td>15</td>
<td>2.00 (a)</td>
<td>2.25 (b)</td>
</tr>
<tr>
<td>30</td>
<td>2.50 (a)</td>
<td>3.50 (b)</td>
</tr>
<tr>
<td>45</td>
<td>4.75 (a)</td>
<td>6.75 (b)</td>
</tr>
<tr>
<td>60</td>
<td>3.25 (a)</td>
<td>5.75 (b)</td>
</tr>
<tr>
<td>101</td>
<td>0.56 (a)</td>
<td>1.70 (b)</td>
</tr>
</tbody>
</table>

Percentage of efficacy (%): 43.7

( ) Newman Keuls’s test (p< 0.05). Difference significant between treated and untreated plots.

The percentage of efficacy of the application of *B. bassiana* was 43.7% (Table 4). This value is very important by considering that, at 30 days after the application of the hyphomycete, it is possible to reduce the 43.7% of the live larvae of *D. saccharalis* that are able to bore into the sugarcane stalk and therefore to cause damage to the crop.

Alves et al. (1985) obtained similar results in Brazil when applying suspensions of conidia of *B. bassiana* at different concentrations in artificially infested plots with *D. saccharalis* larvae.

These authors found 47% and 56% of efficacy and they demonstrated that, in the treated plants, the hyphomycete not only diminished the number of live larvae but also reduced the level of
damage caused by the pest.

Conclusions

ISSR fingerprints provide a useful tool for establishing a rapid and rational approach for differentiating between isolates of entomopathogenic fungi.

In the National Programme of Biological Control against D. saccharalis, it is very important to apply B. bassiana in the field because this imperfect filamentous fungus reduces larval population and the damage caused by this pest.

The results indicate that intermicro-satellites could be used to evaluate the efficacy of different isolates of B. bassiana and their persistence in sugarcane fields. Using these markers, a genetic profile that identifies the most important isolates currently used in the biocontrol of the sugarcane borer in Cuba was obtained.

REFERENCES


CARACTÉRISATION MOLÉCULAIRE DU BEAUVERIA BASSIANA (BALSAMO) VUILLEMIN ET L’APPLICATION DANS LE CONTRÔLE BIOLOGIQUE DU DIATRAEA SACCHARALIS (FABRICIUS)

Par

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MOTS CLÉS: Diatraea saccharalis, Lutte Biologique, Caractérisation Moléculaire, Inter-Microsatellites, Canne à Sucre.

Résumé

L’APPLICATION massive de l’entomopathogène Beauveria bassiana dans les champs de canne est importante dans une perspective agronomique et écologique. Ceci a suscité de l’intérêt pour le développement des outils pour identifier les espèces utilisées. Cette étude avait pour objectifs de caractériser B. bassiana par marqueur moléculaire en utilisant les inter-microsatellites (ISSRs) et d’évaluer l’application du hyphomycète dans la lutte biologique du Diatraea saccharalis (Fabricius). L’ADN génomique a été extrait à partir des mycéliums lyophilisés. Les produits amplifiés ont été analysés avec 100 amorces ISSRs. Un fort pourcentage de polymorphisme (presque 80%) a été observé parmi onze isolats caractérisés avec les quatorze amorces ISSRs sélectionnées. Sept isolats ont produit des bandes uniques avec l’amorce 873 et cela a permis de les différencier. L’application de B. bassiana au champ a réduit le nombre de larves vivant de D. saccharalis par 43.7%, démontrant ainsi le potentiel de l’entomopathogène dans la lutte biologique du foreur de la canne à sucre.

CARACTERIZACIÓN MOLECULAR Y LA APLICACIÓN DE BEAUVERIA BASSIANA (BALSAMO) VUILLEMIN EN EL CONTROL BIOLÓGICO CONTRA DIATRAEA SACCHARALIS (FABRICIUS)

Por

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PALABRAS CLAVES: Diatraea saccharalis, Control Biológico, Beauveria bassiana, Caracterización Molecular, Intermicrosatélites, Cañero.

Resumen

EL INTERÉS agronómico y ecológico de las aplicaciones masivas de B. bassiana precisan de métodos confiables que permitan su identificación en el agrosistema cañero. El presente trabajo tuvo como objetivos la caracterización molecular de B. bassiana por intermicrosatellites (ISSRs) y la evaluación de la aplicación del hifomicete en la lucha biológica contra Diatraea saccharalis (Fabricius). Para ello el ADN genómico fue extraído del micelio lyophilizado. Se analizaron los productos de amplificación con 100 cebadores de ISSRs. El mayor polimorfismo (80%) fue encontrado en 14 de los cebadores ISSR seleccionados. Siete aislamientos diferentes mostraron bandas exclusivas y el cebador SSR 873 distinguió una banda entre todas. La aplicación de B. bassiana en el campo logró disminuir el 43.7% de las larvas vivas del barrenador lo que demostró su potencialidad como agente para el control biológico de esta plaga.
SUGARCANE GENETIC ENGINEERING RESEARCH IN SOUTH AFRICA:
FROM GENE DISCOVERY TO TRANSGENE EXPRESSION

By

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KEYWORDS: \textit{In vitro} Micro-Propagation, Genetic Transformation,
Gene Promoters, Sugarcane.

Abstract

DURING the past 15 years, recombinant DNA and \textit{in vitro} culture technologies have been used in concert at the South African Sugarcane Research Institute (SASRI) to genetically engineer sugarcane. The purpose of such research has been two-fold, \textit{viz.} to establish proof-of-principle regarding the delivery of novel input and resistance traits to sugarcane and to investigate the genetic basis of sucrose accumulation. Underpinning these goals has been the in-house development of essential genetic resources, including the isolation of appropriate transgenes and gene promoter elements, and the optimisation of transformation and tissue culture technologies. With regard to the latter, emphasis has been placed on the development of tissue culture strategies that minimise the potential for somaclonal variation, while maximising the efficiency of germplasm transformation, selection, regeneration and acclimation. The isolation of promoters to drive high-level and targeted transgene expression, as well as the identification of DNA sequences with the potential to deliver the desired phenotype, have been strongly driven by advances in gene discovery and expression technologies. Early approaches relied on the analysis of Expressed Sequence Tag libraries constructed from sugarcane tissues at different developmental stages or challenged with selected abiotic and biotic stress agents. Subsequent improvements in DNA subtractive hybridisation technologies (e.g. suppression subtractive hybridisation) and gene expression analysis (e.g. Affymetrix \textsuperscript{\textregistered} Sugarcane Genome GeneChip) provided new and powerful means for gene and promoter discovery. Reviewed here are the advances in \textit{in vitro} culture, gene discovery and transgene expression research, which have formed the foundation of the genetic engineering program at SASRI. Also discussed are the opportunities and challenges in these areas of research that are presented by the availability of ultra-high throughput DNA sequencing (e.g. the 454 Sequencing System) for transcriptome analysis and technologies for rapid and accurate profiling of the sugarcane metabolomes.

Developing capacity for genetic engineering

Since the release of the first ‘N’ variety, N53/216, in 1964, the South African Sugarcane Research Institute (SASRI) has released 45 varieties that have been bred and selected by conventional means for the five major agro-bioclimatic zones comprising the South African sugar belt.

In the late 1980s, the industry recognised that rapid advances in molecular biology, \textit{in vitro} plant propagation, and recombinant DNA technology offered the potential to serve as powerful adjuncts to conventional breeding; an insight which led to the establishment of a dedicated
biotechnology facility in 1992. The Institute further recognised the value that could be derived from participation in consortia and collaborations to enhance capacities in biotechnology, particularly those pertaining to molecular breeding and genetic engineering.

As a result, SASRI became a founding member of the International Consortium for Sugarcane Biotechnology (ICSB) and entered into agreements with research service providers, such as the Institute for Plant Biotechnology (IPB) at Stellenbosch University, South Africa. The development of in-house capacities at SASRI over the past 15 years, together with outcomes from collaborative and contract research, has led to a thrust in genetic engineering research. Research in this area has focused on establishing Proof-of-Concept for the engineering of resistance and novel input traits, as well as in the investigation of the genetic basis of sucrose accumulation.

Establishing a genetic engineering toolkit

Several technologies and resources are required for effective sugarcane genetic engineering, including: (1) a high throughput plant transformation platform that effectively discriminates for desired transformation events but which also minimises somaclonal variation; (2) sequences of endogenous genes to be targeted for up- or down-regulation and of heterologous genes for the delivery of novel phenotypes; and (3) gene promoters to drive high-level transgene expression that is targeted to the appropriate plant organ or tissue.

Technologies: tissue culture and genetic transformation

In vitro culture is an integral part of plant genetic transformation, with the former technology having been investigated in sugarcane since the late 1960s (e.g. Heinz and Mee, 1969) and which has been recently reviewed by Lakshmanan and co-authors (2005). The availability of such information, together with the protocol for sugarcane transformation described by Bower and Birch (1992), facilitated the development of an effective technology platform for the transformation of South African genotypes (Snyman et al., 1996, 2001a; Snyman, 2004).

Initial protocols for gene delivery involved the use of embryogenic Type 3 callus with morphogenesis proceeding via indirect embryogenesis (Snyman et al., 1996; Snyman, 2004). With these protocols, the time required for the production of a transgenic plant for acclimation ranged between 24 and 36 weeks (Snyman et al., 2000, 2001a). A period of 8 to 12 weeks in culture is required for each of three stages, viz.: callus initiation and proliferation; secondary embryogenesis on a selection agent; and germination of embryos which give rise to transgenic plantlets.

Although this timeframe was considered acceptable in a research and development context, SASRI researchers recognised that a reduction in the culture period would be essential to meet commercial imperatives. It was further recognised that an important additional advantage would result from such a reduction, viz.: reduced duration of exposure to growth hormones would minimise the risk of somaclonal variation.

Consequently, a novel approach for gene delivery was developed at SASRI, based on the use of leaf discs containing floral initials as recipient material, with subsequent plant regeneration via direct embryogenesis (Snyman et al., 2006). Application of this method has resulted in the production of transgenic plants within 14 weeks and also increased the range of germplasm that may be targeted for effective genetic transformation. This high throughput and benign transformation protocol has proven to be an essential element of SASRI’s genetic engineering toolkit.

Genetic resources: accessing transgenes

Over the last 20 years many tools have been developed to study gene structure and function. One of the most powerful of these has been the construction of large public DNA databases, readily accessible via the Internet. When it was demonstrated in the 1980s that partial nucleotide sequences of random clones from cDNA libraries could be aligned to sequence data of known genes contained
in such databases, the capacity for the assignment of putative identities to genes of relatively uncharacterised organisms became a reality. These partial gene sequences, termed Expressed Sequence Tags (ESTs), formed an invaluable resource for research on organisms with complex and non-sequenced genomes, such as sugarcane.

SASRI pioneered EST–based genomic research for sugarcane in the mid 1990s, which was closely followed by similar projects in Australia, USA and Brazil. The SASRI effort was modest in comparison to these later initiatives (Carson and Botha, 2000). For example, Brazilian researchers constructed 26 cDNA libraries from several sugarcane tissues at various stages of development, which yielded a collection of several hundred thousand ESTs (Vettore et al., 2001). SASRI, in contrast, elected to pursue a more targeted strategy, whereby a limited number of cDNA libraries were constructed with a focus on specific targets. As an important SASRI research goal was to determine the genetic basis of sucrose accumulation, considerable effort was devoted to the development of EST libraries that reflected key shifts in gene expression associated with sucrose accumulation.

Two tissue-types were targeted for cDNA library construction, viz. the apical meristem (leaf roll) and maturing culm (internode 7). It was hypothesised that ESTs derived from the meristem would provide access to a wide range of genes associated with growth and development, while those from the maturing internode would provide insights into the identity of genes associated with sucrose accumulation (Carson and Botha, 2000; Carson and Botha, 2002). As expected, meristem ESTs reflected genes encoding products associated with active growth, viz. cell wall synthesis, protein synthesis and protein modification.

Surprisingly, however, the maturing culm yielded very few ESTs depicting enzymes directly associated with sucrose metabolism. Hence, to increase resolution of the EST-based approach, reciprocal subtractive cDNA hybridisation was deployed to enrich for transcripts differentially expressed between internode two (immature) and internode 7 (maturing) (Carson et al., 2002a). Despite this more focused approach, only 10% of ESTs from the subtracted libraries matched genes associated with carbohydrate metabolism; none of which were direct participants in sucrose metabolism. Those results revealed that growth and maturation of the culm is associated with the expression of genes encompassing a wide variety of processes, suggesting that the mechanisms regulating sucrose accumulation were comprised of a complex interplay between various aspects of primary metabolism.

While the SASRI EST collections provided direct access to genes for use in transgenesis, additional value was extracted from the libraries through comparison of EST expression patterns among various target tissues. Central to this research was the in-house development of gene expression profiling strategies based on array screening. Comparative gene expression analyses between tissue-types and developmental stages using membrane-based macroarrays identified a significant number of differentially regulated genes (Carson et al., 2002a, b). These included genes associated with cell wall metabolism, various regulatory and signal transduction processes, as well as a suite of stress-induced genes.

This information, when analysed in concert to data from biochemical and physiological studies, allowed the construction and analysis of custom cDNA macroarrays. Such arrays, sometimes referred to as boutique arrays, were designed using specific ESTs known to encode gene products associated with sucrose metabolism and transport (Watt et al., 2005).

Expression profiling of these ESTs revealed information about key genes and pathways regulating sucrose accumulation. Such array-based gene expression profiling approaches gained considerable momentum after the development of the Affymetrix® Sugarcane Genome GeneChip (Affymetrix chip); an important innovation driven by Casu et al. (2006) in Australia. Using this resource, researchers at SASRI have examined the role of sugar sensing and signalling in mediating
the source-sink relationship in sugarcane (McCormick et al., 2006). That work revealed a potentially central role of trehalose metabolism in the sink-mediated modulation of photosynthetic activity (McCormick et al., 2008). Work is currently in progress to unravel further the relationship that may exist between the capacity of the sugarcane plant to modulate sucrose production in the leaf according to the demand for the sugar by the stalk. In this regard, a combination of Suppression Subtractive Hybridisation (SSH) and ultra-high throughput DNA sequencing, based on 454-technology, is proving pivotal.

**Genetic resources: isolating gene promoters**

Gene promoters are an essential component of any genetic engineering toolkit, as they are required to regulate transgene expression to an appropriate level and to target expression to the desired site within the plant. The unavailability in the public domain of suitable promoters to drive high-level tissue- or organ-specific transgene expression in South African sugarcane germplasm prompted SASRI to establish a promoter isolation research programme. The overall strategy used in this endeavour has three components, viz.: (1) identification of transcripts displaying a suitable tissue-specific expression pattern; (2) identification and isolation of the corresponding promoter region from genomic DNA; and (3) functional assessment of the promoter in planta. In this regard, SASRI has sought to isolate functional promoters for targeting transgene expression to the leaf, culm or root.

Identification of tissue-specific transcripts has relied on the macroarray and the SSH technologies that were developed and deployed in SASRI’s early EST research. More recently, the Affymetrix chip technology has also been used to good effect in detecting differentially expressed genes to serve as a basis for promoter discovery. However, further validation of the differential gene expression patterns, detected by these technologies, is a vital step prior to promoter isolation. To this end, SASRI researchers have used two validation protocols, viz. (1) virtual confirmation of laboratory observations using the numerous online tools and data available at the National Centre for Biotechnology Information; and (2) experimental confirmation using either northern hybridisation analysis or quantitative PCR (qPCR), with the latter being the current method-of-choice.

Initial promoter isolation approaches at SASRI used the nucleotide sequences of well-characterised differentially expressed genes to retrieve the corresponding promoter region from the sugarcane genome. Such retrieval was based on the screening of sugarcane genomic libraries, which were either in the form of Bacterial Artificial Chromosome (BAC) or bacteriophage libraries.

Numerous conceptual and practical challenges arose during the screening of such libraries, primarily as a result of the complex, polyploid nature of the sugarcane genome. These challenges included accounting for the potential presence in the genome of multiple pseudogenes with associated non-functional promoter sequences, in addition to allelic promoter variants with different levels of activity.

Of additional concern was the propensity for gene silencing in sugarcane observed at SASRI and also reported in the literature (Hansom et al., 1999, Mudge et al., 2009). Hence, to-date, the maize Ubi-1 promoter (Christensen and Quail, 1996) remains the most widely used plant-derived promoter for sugarcane transformation, primarily due to the difficulties encountered by many research groups in isolating promoters that are capable of stable and high-level transgene expression (Brumbley et al., 2008). To reduce the risk of promoter silencing by transcriptional gene silencing (TGS) events, a strategy has been implemented at SASRI to isolate tissue-specific promoters from close *Saccharum* relatives, viz. *Sorghum bicolor* and *Zea mays*, for use in sugarcane. Availability of the sorghum genome sequence (Paterson et al., 2009) has made this approach particularly efficient, in that promoter regions are easily targeted for PCR-mediated amplification by means of sequence-specific oligonucleotide primers.
As transient expression assays do not necessarily depict in planta promoter expression characteristics, the functionality of promoters isolated at SASRI was assessed in numerous plants regenerated from multiple transgenic events. The rapid in vitro propagation and genetic transformation protocols developed greatly assisted in the generation of the large numbers of transgenic plants required for promoter functional testing. Results obtained to-date indicate that overcoming the phenomenon of TGS remains a challenge. As a result, SASRI researchers are currently exploring ways to alleviate promoter methylation, which is a recognised cause of transgene silencing. A construct, pKOMet, is being used to alter the expression of the endogenous sugarcane DNA methyltransferase, while the efficacy of a construct bearing a viral suppressor of gene silencing, pUbi P1/HcPro is also under evaluation. The availability of tissue-specific promoters to drive high-level transgene expression will be an extremely valuable tool in SASRI’s genetic engineering research.

Establishing Proof-of-Concept: examples from SASRI’s research portfolio

Proof-of-Concept for transgenesis was first generated at SASRI using herbicide resistance conferred by the pat gene from Streptomyces viridochromogenes against the herbicidal compound glufosinate ammonium (Leibbrandt and Snyman, 2003) (Table 1). Gene constructs were delivered by microprojectile bombardment and selection was facilitated by the nptII gene using G418 or paromomycin as selection agents (Snyman, 2004). Gene expression of both the gene of interest and the selectable marker was driven by the maize ubiquitin promoter. Subsequent field trials with selected herbicide resistant lines established that the pat transgene was stably inherited and expressed over multiple ratoons (Leibbrandt and Snyman, 2003). Since that initial study, two additional Proof-of-Concept projects, focusing on the delivery to elite South African sugarcane germplasm of input and resistance traits, have been successfully completed, viz. (1) increased resistance to the sugarcane stem borer, Eldana saccharina, through expression of the Cry1A(c) δ-endotoxin gene from Bacillus thuringiensis and (2) tolerance of the herbicide, glyphosate, through expression of a transgene derived from Agrobacterium sp. strain CP4 encoding the enzyme 5-enolpyruvyl-shikimate-3-phosphate synthase (Table 1).

Technologies to modify the expression of genes encoding key enzymes of carbohydrate metabolism in sugarcane have generated insights into the complex biochemical, metabolic and physiological processes underlying sucrose accumulation. This research area at SASRI has benefited from a strong collaboration with the IPB at Stellenbosch University, as well as from data generated from the early EST and gene expression experiments. For example, the gene encoding UDP-glucose dehydrogenase (UDPG-DH) was shown to be preferentially expressed in the immature culm (Carson et al., 2002a). Using this information as a starting point, research has been conducted to down-regulate UDPG-DH activity using antisense and RNAi technologies (Bekker, 2007) (Table 1). It was hypothesised that assimilated carbon would be directed away from cell wall synthesis and towards sucrose synthesis. Internodes from transgenic lines grown under glasshouse conditions demonstrated an increase in sucrose content that was correlated with a decrease in UDPG-DH activity. Currently, several other lines with modified levels of key enzymes of sucrose metabolism, which demonstrated desirable phenotypes in cell suspension culture and under glasshouse conditions, are under analysis in field trials (Table 1).

Future directions

The application of genetic engineering technology at SASRI has yielded several invaluable outcomes, including Proof-of-Concept for the delivery of beneficial input and resistance traits, as well as insights into the regulation of sucrose accumulation.

As the prospect of commercial production of transgenic sugarcane becomes increasingly less distant, SASRI management and researchers have begun to focus their efforts on issues that will ultimately facilitate the realisation of that goal. Such issues include refinement of
transformation technologies and addressing, as far as is possible, the socio-political, freedom-to-operate and regulatory issues surrounding genetic engineering with a commercial intent.

Refinements to the genetic engineering toolkit currently underway at SASRI encompass the development of: (1) transformation protocols that offer an alternative to biolistics; (2) benign selection methodologies for transformation events; and (3) novel approaches to isolate promoters which are not susceptible to TGS.

**Table 1**—Novel input traits, resistance traits and modified sucrose metabolism conferred via transgenesis to South African sugarcane germplasm. Also reflected are the nature and source of transgenes and the extent to which transgenic lines have been characterised to-date.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Gene and nature of modification</th>
<th>Source of gene</th>
<th>Stage of assessment</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Novel input trait</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Herbicide resistance:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>glufosinate ammonium</td>
<td>pat gene: heterologous</td>
<td>Streptomyces</td>
<td>Field trial* (five</td>
<td>Leibbrandt and Snyman</td>
</tr>
<tr>
<td>glyphosate</td>
<td>heterologous expression</td>
<td>Agrobacterium</td>
<td>trial* (two ratoons)</td>
<td>Snyman * et al.* (2001b)</td>
</tr>
<tr>
<td>Resistance traits</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Insect resistance:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eldana saccharina (Lepidoptera: Pyralidae)</td>
<td>Cry1A(c): heterologous expression</td>
<td>Bacillus</td>
<td>Pot bioassay:</td>
<td>Unpublished</td>
</tr>
<tr>
<td>Virus resistance:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Sugarcane Mosaic Potyvirus (SCMV))</td>
<td>SCMV Coat Protein: heterologous expression in antisense and untranslatable forms</td>
<td>SCMV Strain D</td>
<td>Natural infestation</td>
<td>Sooknandan (2002); Sooknandan * et al. (2003)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>field trial* (two</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>ratoons)</td>
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<tr>
<td><strong>Modification of sucrose metabolism</strong></td>
<td></td>
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<td></td>
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<tr>
<td>Enzyme and transporter targets</td>
<td></td>
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<tr>
<td>Neutral invertase (NI)</td>
<td>NI gene: down-regulation of</td>
<td>Saccharum spp hybrid var NCo310</td>
<td>Performance evaluated under glasshouse conditions and in cell suspension culture.</td>
<td>Roussow * et al. (2007)</td>
</tr>
<tr>
<td></td>
<td>endogenous gene by anti-sense</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>expression</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>UDP-glucose dehydrogenase</td>
<td>UDPG-DH gene: down-regulation</td>
<td>Saccharum spp hybrid var NCo310</td>
<td>Performance evaluated under glasshouse conditions</td>
<td>Bekker (2007); Patent number 2006/07743</td>
</tr>
<tr>
<td>(UDP-DH)</td>
<td>of endogenous gene by RNAi and</td>
<td></td>
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<tr>
<td></td>
<td>anti-sense expression</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>H&quot;+-translocating vacuolar pyrophosphatase (VPPase)</td>
<td>VPPase gene: overexpression of endogenous gene</td>
<td>Saccharum spp hybrid var NCo310</td>
<td>Performance evaluated under glasshouse conditions</td>
<td>Swart (2007); Patent number 2007/02680</td>
</tr>
</tbody>
</table>

* Field trials conducted under permit from the South African National Department of Agriculture, Directorate: Biosafety, in accordance with the GMO Act 15 of 1997.

In parallel to these practical issues, researchers are beginning to draw on the potential offered by ultra-high throughput technologies, such as those for nucleotide sequencing and metabolite profiling, for potential application to gene discovery and demonstration of substantive equivalence of transgenic lines to wild-type. SASRI’s genetic engineering research is conducted in
a favourable environment, in that the South African sugar industry is supportive and the national regulatory framework is well-established. Given this context, the expertise held by SASRI and the availability of an established repertoire of technologies, the future for sugarcane genetic engineering research in South Africa holds considerable promise.

REFERENCES


LA RECHERCHE EN GÉNIE GÉNÉTIQUE EN AFRIQUE DU SUD : DE LA DÉCOUVERTE DU GÈNE À L’EXPRESSION DU TRANSGÈNE

Par

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MOTS CLÉS: Micro-Propagation In Vitro, Transformation Génétique, Promoteurs des Gènes, Canne à Sucre.

Résumé

DURANT LES 15 dernières années, les technologies de l’ADN recombiné et de la culture in vitro ont été utilisées au South African Sugar Research Institute (SASRI) pour la transformation génétique de la canne à sucre. Cette recherche avait un double but : établir la preuve de principe concernant le transfert de nouveaux traits de production et de résistance à la canne à sucre, et examiner le mécanisme génétique responsable de l’accumulation de saccharose. Pour atteindre ces objectifs, il a été nécessaire de développer en laboratoire les techniques essentielles, y compris, l’isolation des transgènes et promoteurs appropriés, l’optimisation des technologies du génie génétique et de la culture de tissus. Concernant la culture de tissus, l’accent a été mis sur les stratégies qui minimisent le potentiel de variation somaclonale, tout en maximisant l’efficacité de la transformation du germoplasme, la sélection, la régénération et l’acclimatation. L’isolation des promoteurs pour une forte expression du transgène ciblée, et l’identification des séquences d’ADN qui ont le potentiel de développer le phénotype recherché, ont fortement évoluées de par les avancées dans la découverte des gènes et leur expression. Les approches initiales dépendaient de l’analyse des banques d’étiquettes de séquences exprimées (EST) produites à partir des tissus de canne à sucre de différents stades de développement ou qui ont été soumis à des stress biotiques et abiotiques. Des améliorations ultérieures des technologies d’hybridation soustractive d’ADN (e.g. hybridation soustractive et suppressive) et de l’analyse de l’expression génique (e.g. Affymetrix® Sugarcane Genome Genechip) ont apporté des moyens nouveaux et puissants pour la découverte de gènes et de promoteurs. Les avancées dans la culture in vitro, la découverte de gènes et l’expression de transgènes, qui ont formé la base du programme de génie génétique au SASRI, sont revues ici. Les opportunités et les défis dans ce domaine de recherche, grâce à la disponibilité de séquençage d’ADN à ultra haut débit (e.g. le Système 454 de Séquençage) pour l’analyse du transcriptome, et les technologies pour établir un profil rapide et précis des métabolomes de la canne à sucre sont aussi discutés.
INVESTIGACIÓN EN ÁFRICA DEL SUR SOBRE INGENIERÍA GENÉTICA DE LA CAÑA DE AZÚCAR: DEL DESCUBRIMIENTO GENÉTICO A LA EXPRESIÓN TRANSGÉNICA

Por

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PALABRAS CLAVE: Micro-Propagación \textit{In Vitro}, Transformación Genética, Promotores Genéticos, Caña de Azúcar.

Resumen

DURANTE los últimos 15 años, las tecnologías de ADN recombinante y de cultivo \textit{in vitro} han sido utilizadas en combinación en el Instituto de Investigación en Caña de Azúcar de África del Sur (SASRI, por sus siglas en Inglés) para innovar genéticamente a la caña de azúcar. El propósito de tal investigación es doble, \textit{viz.} establecer pruebas contundentes de la incorporación de nuevos caracteres y de aquellos de resistencia, e investigar la base genética de la acumulación de sacarosa. Tales objetivos han sido sustentados por el desarrollo interno de recursos genéticos cruciales, incluidos el aislamiento de transgenes y elementos de promoción genética adecuados, y la optimización de las tecnologías de transformación y en el cultivo de tejidos. Con respecto de lo último, se ha enfatizado en el desarrollo de estrategias en el cultivo de tejido para minimizar el potencial de variación somaclonal, a la par de maximizar la eficiencia en la transformación de germoplasma, la selección, la regeneración y la aclimatación. El aislamiento de promotores para impulsar un alto nivel y el destino de la expresión transgénica, así como la identificación de secuencias de ADN para asegurar la obtención del genotipo deseado, han sido fuertemente impulsados por avances tecnológicos en el descubrimiento y expresión genéticos. Los esfuerzos iniciales dependían del análisis de las bibliotecas de Etiquetas de Secuencias Expresadas (EST, por sus siglas en Inglés) derivadas de tejidos de caña de azúcar en distintos estados de desarrollo o sometidas a agentes selectos de estrés abiótico y biótico. Mejoras subsecuentes en tecnologías de hibridación substractiva (p.e., supresión de hibridación substractiva) y en el análisis de la expresión genética (p.e., \textit{Chip} Affymetrix\textsuperscript{\textregistered} de Genes de la Caña de Azúcar) han provisto de nuevos y poderosos medios para el descubrimiento de genes y promotores. Aquí se revisan los avances en el cultivo de tejidos, el descubrimiento de genes y la investigación en la expresión transgénica, los cuales han significado el fundamento del programa de ingeniería genética en el SASRI. Asimismo, se debaten las oportunidades y retos en las áreas de investigación aquí expuestas debido a la disponibilidad en la secuenciación de alto procesamiento del ADN (p.e., el sistema de secuenciación 454) o el análisis en el transcriptomo y en tecnologías para la definición rápida y precisa del perfil de los metabolomas de la caña de azúcar.
IDENTIFICATION OF MICROSATELLITE MARKERS ASSOCIATED WITH YIELD COMPONENTS AND QUALITY PARAMETERS IN SUGARCANE

By

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KEYWORDS: QTL, Molecular Markers, Yield Components, Quality Parameters.

Abstract

MARKER assisted selection depends on the identification of tightly linked association between marker and the trait of interest. In the present work, functional (EST-SSRs) and genomic (gSSRs) microsatellite markers were used to detect putative QTLs for sugarcane yield components (stalk number, diameter and height) and as well as for quality parameters (Brix, Pol and fibre) in plant cane. The mapping population (200 individuals) was derived from a bi-parental cross (IACSP95-3018 x IACSP93-3046) from the IAC Sugarcane Breeding Program. As the map is under construction, single marker trait association analysis based on the likelihood ratio test was undertaken to detect the QTLs. Of the 215 single dose markers evaluated (1:1 and 3:1), 90 (42%) were associated with putative QTLs involving 43 microsatellite primers (18 gSSRs and 25 EST-SSRs). For the yield components, 41 marker/trait associations were found: 20 for height, 6 for diameter and 15 for stalk number. An EST-SSRs marker with homology to non-phototropic hypocotyls 4 (NPH4) protein was associated with a putative QTL with positive effect for diameter as also with a negative effect for stalk number. In relation to the quality parameters, 18 marker trait associations were found for Brix, 19 for Pol, and 12 for fibre. For fibre, 58% of the QTLs detected showed a negative effect on this trait. Some markers associated with QTLs with a negative effect for fibre showed a positive effect for Pol, reflecting the negative correlation generally observed between these traits.

Introduction

The identification of molecular markers tightly linked to agronomic traits of breeders’ interest is an important step to make possible the implementation of marker assisted selection in a breeding program (Morgante and Salamini, 2003; Charcosset and Moreau, 2004).

Besides this practical application, molecular markers are also suitable to study the genetic architecture of agronomic traits, especially the complex ones (quantitative traits) that can be resolved into single Mendelian components.

Sugarcane is an important cash crop with a complex genome that, certainly, will benefit from molecular marker technology, as most of its agronomic traits have a multigenic and/or multi-allelic nature. Several QTLs have been detected for basic yield components such as plant weight,
stalk number, stalk diameter and also for Brix and suckering through molecular mapping involving sugarcane bi-parental crosses (Hoarau et al. 2002; Jordan et al. 2004; Reffay et al., 2005; Aitken et al., 2008). The identification of genomic regions responsible for a phenotype of a trait probably will be accelerated by the utilisation of molecular markers derived from expressed sequence tags (ESTs). This type of marker can provide the direct mapping of genes while, at the same time, they themselves may be responsible for the trait of interest (Cato et al., 2001).

EST databases, such as the Sugarcane EST (SUCEST), have been used in the development of molecular markers for mapping (Oliveira et al., 2007) and QTL detection (Pinto et al., 2009) in sugarcane. Microsatellites, as co-dominant markers, have a great potential to allow the comparison among sugarcane maps from different mapping populations. Nowadays, several microsatellites derived from ESTs (EST-SSRs) are available for sugarcane (Oliveira et al., 2009) and together with the genomic ones (Cordeiro et al., 2000) will extend the access to the sugarcane genome, especially to the expressed ones.

In the present work, functional (EST-SSRs) and genomic (gSSRs) microsatellite markers were used to detect putative QTLs for sugarcane yield components (stalk number, diameter and height) as also for quality parameters (Brix, Pol and fibre) in plant cane. As the map is under construction, single marker trait association analysis based on the likelihood ratio test was undertaken to detect putative QTLs at $P < 0.05$.

**Material and methods**

**Mapping population and field data**

The mapping population was composed of 200 individuals derived from a bi-parental cross between the elite clone IACSP95-3018 (female parent) and the variety IACSP93-3046 (male parent) from the IAC Sugarcane Breeding Program. The progeny were planted in July 2005 at IAC Sugarcane Station in Ribeirão Preto in an augmented randomised block design, with five replications and including varieties SP81-3250 and RB835486 as controls.

Yield components (stalk number, stalk diameter and stalk height) as well as Brix and Pol (Pol value; gram of sucrose /kg/100g of fresh cane) and fibre percent were collected for each genotype at harvest in plant cane in August 2006. Stalk number was counted in one metre plot. Stalk diameter was measured in a sample of 5 stalks in the middle of the internode (one third of the stalk height from the base to the top).

The same sample was also used for the stalk height measurement conducted with a tape measure. The phenotypic data of each clone was adjusted for differences among blocks by the SAS statistical package (SAS Institute Inc., NC, USA).

**Microsatellite analysis**

Total genomic DNA was extracted from 300 mg of powdered lyophilised young leaf tissues using a CTAB-method (Hoisington et al., 1994) modified for sugarcane. PCR reactions were performed in a 20 µL final volume containing 40 ng of template DNA, 0.2 µM of each forward and reverse primer, 100 µM of each dNTP, 2.0 mM MgCl₂, 10mM Tris-HCl, 50 mM KCl, and 0.5 Unit Taq DNA polymerase. Reactions were amplified as follows: 94°C for 3 min; followed by 30 cycles of 94°C for 1 min; annealing temperature specific for each primer for 1 min; extension of 72°C for 1 min and a final elongation step at 72°C for 2 min. Amplification products were separated by electrophoresis on 6% denatured polyacrylamide gels and using a 25-bp ladder as size standard and silver-staining according to Creste et al. (2002).

**Single-marker trait association analyses**

Marker segregation types were identified in a chi-square test for deviations from the expected segregation ratios of 1:1 and 3:1 (markers in single-dose in only one of the parents and markers in single-dose in both parents, respectively) with Bonferroni correction to control type I error for multiple tests. Markers were identified by the name of the SSRs plus a number according
to the fragment size (molecular weight) followed by a letter to denote parent polymorphism origin: D1 for marker present on ISCSP95-3018, D2 marker present on IACSP93-3046 and C for marker present in both parents.

Associations between the 215 single dose markers evaluated and QTL for yield components and quality parameters were done by comparing, through a likelihood ratio, the full regression model \( Y_j = \mu + bx + \epsilon_j \) assuming a lack of association between marker and QTL \((b = 0)\) (QTL search). The criteria adopted to declare putative marker-trait associations were p-values smaller than 0.05 and 0.01 (not correcting for multiple tests). The 215 single dose markers were derived from 43 microsatellite primers, of which, 18 genomic and 25 functional were chosen at random.

**Results and discussion**

The genetic map of the population used in the present work is under construction and therefore the number of single dose markers available until now is insufficient for a QTL mapping analysis. Thus, a single marker trait association analysis based on the likelihood ratio test (Liu, 1998) was undertaken to give previous information of putative QTL associations without the need of a genetic map. Moreover, this approach allowed maker trait association for all single dose markers obtained to be investigated.

**Single-marker trait associations**

Ninety marker trait associations \((P < 0.05)\) were found for the phenotypic measures obtained on plant cane of which 14 \((15%)\) were found at 1\% \((P < 0.01)\) significance level and 11 \((121%)\) at 0.5\% \((P < 0.005)\) significance level. These 90 putative marker trait associations represented 42\% of the total single dose markers evaluated in the single-marker analysis.

The number of associations detected \((90)\) exceeded the average number of statistical false positive association that might exist due to statistical chance. A statistical average of 64 potential false positive associations due to statistical chance is assumed at \(P<0.05\) \((0.05 \times 215 \text{ markers} \times 6 \text{ traits})\).

**Putative QTLs for yield components**

The range of the progeny phenotypic values ranged from 5 to 30 for stalk number (average of 14.14 ± 4.04), from 1.77 to 3.43 cm for stalk diameter (average of 2.71 ± 0.32 cm) and 0.93 to 3.29 m for stalk height (average of 2.36 ± 0.39 m).

For the phenotypic evaluations related to the yield components (height, diameter and stalk number), 41 marker associations were found: 20 \((17.8\%)\) for height, 6 \((5\%)\) for diameter and 15 \((13\%)\) for stalk number. Of the total number of markers associated with height, 6 \((30\%)\) showed a negative effect on this trait. SCA17.1C marker was associated either for height or diameter, with negative effect on both traits.

For stalk number, 8 \((53\%)\) markers showed negative effect contributing to reduction in tillering. Cir32.5D2 marker derived from IACSP93-3046 \((D2)\) parent had a high positive effect on stalk number \((7.48 \text{ stalks})\). SCB130.1D1 marker was associated with a putative QTL with positive effect \((0.13 \text{ cm})\) for diameter and negative \((-1.40 \text{ stalks})\) for stalk number (Table 1) reflecting the negative correlation usually observed between diameter and stalk number. Moreover, SCB130.1D1 marker is derived from an EST with homology to a hypocotyl protein.

**Putative QTLs for cane quality parameters**

For the quality parameters 18 \((20\%)\) single dose markers were found associated with putative QTLs for Brix, 19 \((21\%)\) for Pol and 12 \((13.3\%)\) for fibre. Of the markers associated with Brix putative QTLs, 11 were also found associated with Pol with similar effect values and direction \((i.e. \text{ increase or decrease in the effect})\).

In relation to fibre, 58\% of the putative QTLs identified had a negative effect on this trait. The SCB27.3C marker was associated with a QTL with negative effect for fibre \((\text{reduction of} -0.91\% \text{ in fibre})\) and also to a QTL with positive effect \((\text{increase of} 0.49 \text{ Pol}%)\) for Pol.
**Table 1**—Single marker analysis for stalk height, stalk diameter (SD), stalk number (SN) and quality parameters (brix, Pol and fibre) in plant cane.

<table>
<thead>
<tr>
<th>Markers</th>
<th>Homology</th>
<th>Height</th>
<th>SD</th>
<th>SN</th>
<th>Brix</th>
<th>Pol</th>
<th>Fibre</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC80.4D2</td>
<td>Lamin</td>
<td>--</td>
<td>--</td>
<td>-1.23*</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>SG47.1C</td>
<td>Aminotransferase protein</td>
<td>--</td>
<td>--</td>
<td>-1.49*</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>CV37.3C</td>
<td></td>
<td>--</td>
<td>1.69*</td>
<td>--</td>
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<td>--</td>
</tr>
<tr>
<td>SC61.1D2</td>
<td>Root specific protein ZRP3</td>
<td>--</td>
<td>--</td>
<td>-1.29*</td>
<td>0.33*</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>SC44.1C</td>
<td>Ubiquitin-specific protease</td>
<td>--</td>
<td>--</td>
<td>1.99*</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>SC130.1D1</td>
<td>Non-Phototropuc hypocotyl protein</td>
<td>0.13***</td>
<td>-1.40*</td>
<td>-0.39*</td>
<td>--</td>
<td>-0.55*</td>
<td></td>
</tr>
<tr>
<td>SC130.1D1</td>
<td>Non-Phototropuc hypocotyl protein</td>
<td>0.14***</td>
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</tr>
<tr>
<td>SC30.4C</td>
<td></td>
<td>0.13***</td>
<td>--</td>
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<td>--</td>
</tr>
<tr>
<td>SC14.1C</td>
<td>LRR transmembrane protein kinase</td>
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*Significance level at 5% (P<0.05). ** Significance level at 1% (P<0.01). *** Significance level at 0.5% (P<0.005). D1: Single dose in IACSP95-3018. D2: Single dose in IACSP93-3046. C: Single dose in both parents. In parenthesis number of marker trait associations detected at (P<0.01) and (P<0.005), respectively.
The same trend was observed for SCA48.1D2 marker that was not only associated with a QTL with a positive effect for Brix and Pol but also with a QTL with negative effect for stalk number.

**Biochemical relationship between marker homology and putative QTL detected**

The utilisation of molecular markers derived from ESTs allowed the investigation of the biochemical relationship between the role of the gene used as marker and the respective associated agronomic trait.

In our study, the relationship was investigated *a posteriori* as the EST-SSRs were chosen at random. Some of the putative QTL detected were associated with markers, which could be related with the phenotype evaluated.

For example, marker SCB58.7D1 having homology to Myb-like protein was associated with fibre. Some MYB genes have been shown to be involved in the control of phenylpropanoid metabolism involved in lignin production.

Marker SB130.1D1 associated with stalk diameter, stalk number and Brix has homology with a non-phototropic hypocotyl protein (NPH4) that encodes the auxin-regulated transcriptional activator ARF7 (AUXIN RESPONSE FACTOR 7), which is conditionally required for the modulation of differential growth of aerial tissues in *Arabidopsis* (Harper *et al.*, 2000).

**Acknowledgments**

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**REFERENCES**


Identification de marqueurs microsatellites associés aux composantes du rendement et aux paramètres de qualité chez la canne à sucre

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MOTS-CLÉS: QTL, Marqueurs Moléculaires, Composantes de Rendement, Paramètres de Qualité.

Résumé
La sélection assistée par marqueurs dépend d’une étroite association entre le marqueur et le caractère à l’étude. Des marqueurs fonctionnels (EST-SSRs) et génomiques (gSSRs) ont été utilisés dans cette étude pour déterminer d’éventuels QTLS associés aux composantes de rendement (nombre de tiges, diamètre et hauteur) et aux paramètres de qualité (Brix, Pol et fibre) chez la canne vierge. Une descendance de 200 individus issue d’un croisement bi-parental (IACSP95-3018 x IACSP93-3046) provenant du IAC Sugarcane Breeding Program a été utilisée pour l’étude cartographique. Étant donné que la carte génétique n’a pas encore été réalisée, une association de marqueurs à caractère simple (single marker trait association), basée sur le test du rapport de vraisemblance (likelihood ratio test), a été utilisée pour déterminer les QTLS. Des 215 marqueurs simplex (ratio 1:1 et 3:1) identifiés à l’aide de 43 amorces microsatellites (18 gSSRs et 25 EST-
IDENTIFICACIÓN DE MARCADORES MICROSATÉLITES ASOCIADOS CON COMPONENTES DE RENDIMIENTO Y PARÁMETROS DE CALIDAD EN LA CAÑA DE AZÚCAR

Por

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PALABRAS CLAVE: QTL, Marcadores Moleculares, Componentes de Rendimiento, Parámetros de Calidad.

Resumen

LA SELECCIÓN asistida por marcadores depende de la identificación de una fuerte asociación de ligamiento entre marcadores y carácter de interés. En el presente trabajo, marcadores funcionales (EST-SSRs) y genómicos (gSSRs) fueron usados para detectar QTLs putativos para componentes de rendimiento de la caña de azúcar (número de tallos, diámetro y altura), así como para parámetros de calidad (Brix, Pol y fibra) en planta de caña de azúcar. La población a cartografiar (de 200 individuos) fue derivada de una cruza bi-parental (IACSP95-3018 × IACSP93-3046) del Programa de Fitomejoramiento de Caña de Azúcar del IAC. Ya que el mapa se encuentra bajo construcción, un análisis de asociación entre carácter y marcadores únicos fue efectuado para detectar los QTLs, basado en una prueba de probabilidad. De los 215 marcadores de una sola dosis (1:1 y 3:1), 90 (42%) fueron asociados con QTLs putativos involucrando 43 iniciadores microsatélite (18 gSSRs y 25 EST-SSRs). Para los componentes de rendimiento, 41 asociaciones fueron encontradas entre marcadores y carácter: 20 para altura, 6 para diámetro y 15 para número de tallos. Un marcador EST-SSR con homología a la proteína 4 (NPH) del hipocotilo no fototrópico fue asociada con un QTL putativo de efecto positivo para el diámetro, así como con un efecto negativo para el número de tallos. En relación con los parámetros de calidad, 18 asociaciones entre marcadores y caracteres fueron encontrados para el Brix, 19 para el Pol y 12 para la fibra. Para la fibra, 58% de los QTLs detectados mostraron un efecto negativo en este carácter. Algunos marcadores asociados con un efecto negativo para la fibra mostraron un efecto positivo para Pol, reflejando una correlación negativa generalmente observada entre ambos caracteres.
COMPARISON OF AFLP, TRAP AND SSRs IN THE ESTIMATION OF GENETIC RELATIONSHIPS IN SUGARCANE

By

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KEYWORDS: Molecular Markers, Genetic Distance, Sugarcane.

Abstract
The sugarcane Breeding Program of the Instituto Agronômico de Campinas has been using routinely different types of molecular markers for the characterisation of their breeding clones and varieties. In the present work, we compared the genetic relationships among 82 sugarcane clones/varieties using three types of molecular markers: AFLP, TRAP and Microsatellites (SSRs). Five AFLP selective primer combinations, 10 SSRs and four TRAP fixed primers, designed from candidate genes involved in the drought tolerance response metabolism, were used in combination with three arbitrary primers. The pair-wise genetic similarity based on the Jaccard’s coefficient, the dendrogram and matrix comparison were done using NTSYS Software. A total of 410 polymorphic markers were obtained: 145 AFLPs, 103 SSRs, and 160 TRAPs. Although the average genetic similarity estimates based on AFLP (0.675) and TRAP (0.655) were closer to each other than to SSRs (0.522), the correlation between TRAP and SSRs was higher (r= 0.24). The coefficient of variation was lower for AFLP and TRAP (~6.55%) than for SSRs (13%). These results indicate that the choice of molecular markers should be considered carefully, based on the purpose of the application in the breeding program, as it is not possible to select a marker system that fits all the requirements for germplasm characterisation.

Introduction
Molecular markers are essential tools in breeding programs. One of their applications is to allow the estimation of the genetic distance (GD) among elite genotypes. Genetic distance estimation revealed by molecular markers should be prioritised for crops like sugarcane, with narrow genetic base, unknown ancestors, and with no accurate or even non-existing pedigree records (Farooq and Azam, 2002). In sugarcane breeding, the choice of parents is based on agronomic traits and pedigree records, using bi-parental crosses or polycrosses among elite genotypes.

However, the lack of genealogy data, as well as errors in the identification of some genotypes has resulted in inaccurate estimation of genetic distance among sugarcane genotypes based on pedigree data. It is accepted that crosses between unrelated genotypes would maximise the number of segregating alleles resulting in a large genetic variance of the progeny (Cox et al., 1985; Messmer et al., 1993), thus increasing the probability of selecting rare and superior genotypes (Becelare et al., 2005). The genetic variability within sugarcane germplasm has been estimated using different molecular markers, including random (Lima et al., 2002, Aitken et al., 2006) and functional marker systems (Pinto et al., 2006; Alwala et al., 2006).
Molecular markers are used routinely at the Instituto Agronômico de Campinas as an additional tool to assess the genetic variability among genotypes used as parents. They are also used to fingerprint commercial and pre-commercial clones and to monitor for genetic identity in germplasm collections and in commercial fields. The objectives of this study were to evaluate the usefulness of microsatellite (SSR), amplified fragment length polymorphism (AFLP) and target region amplification polymorphism (TRAP) markers in the estimation of the genetic similarities (GS) in a specific set of sugarcane genotypes and to compare the GD values among them.

Material and methods

Plant material and DNA extraction

A total of 82 genotypes, comprising commercial and pre-commercial clones, were used. These represented a set of specific genotypes issued from the ‘Centro de Cana’ sugarcane breeding program, that are being evaluated in the field under the Brazilian ‘cerrado’ (savanna) conditions for drought response. From each genotype, total DNA was extracted from a fresh meristem cylinder (Ali et al., 1999).

Primers used

TRAP markers were obtained from four fixed primers designed from candidate genes involved in the drought tolerance response metabolism (Aquaporin – Aqua primer; late embryogenesis abundant protein – LEA primer; dehydration binding factor – DBF primer; and dehydration responsive binding elements – DREB primer) in combination with three arbitrary primers (referred to as arb1, arb2 and arb3 primers) provided by Li and Quiros (2001). TRAP PCR reactions were performed according Alwala et al. (2006).

AFLP analysis was carried out using five primer combinations (E-ACT/M-CAT, E-ACG/M-CTT, E-ACG/M-CTC, E-ACT/M-CAG, E-AGA/M-CTG), according Vos et al. (1995). A total of 10 SSRs (6 genomic and 4 derived from expressed sequence tags) were chosen based on the sugarcane functional map (Oliveira et al., 2007). The primer sequences and amplification conditions of genomic SSR and EST-SSRs were obtained, respectively, from Pan (2006) and Oliveira et al. (2009). The polymorphisms were detected in polyacrylamide gels by silver staining (Creste et al., 2001).

Data analysis

Amplified fragments were scored for presence (1) or absence (0) in all 82 genotypes. The genetic similarities among all genotypes were calculated according to Jaccard’s similarity coefficient using NTSYS-PC version 2.0j (Exeter Software, Setauket, NY, USA). The polymorphic information content (PIC) for allelic diversity at a given locus was measured. As PIC for dominant markers ranges from 0 to 0.5 and for co-dominant markers from 0 to 1.0, the PIC values obtained for AFLP and TRAP were converted in PIC % to allow comparison among the different marker types.

Results and discussion

The genetic polymorphism of 82 sugarcane genotypes was assessed by TRAP, AFLP and SSR markers. The data obtained for each marker type, in terms of total number of markers analysed, number of polymorphic markers; percent of polymorphism and PIC value are summarised in Table 1.

Target region amplification polymorphisms (TRAP)

The 12 TRAP primer combinations produced a total of 225 fragments, of which 160 (71.11%) were polymorphic. The total number of bands amplified by individual primer combinations ranged from 14 (DREB/Arb3 and LEA/Arb1) to 27 (Aquaporin + Arb3), an average of 18.75 bands per primer combination, and 13.30 polymorphic bands per primer combination. The highest number of polymorphic fragments was observed with primer combination DBF/Arb1 (18 fragments) and the lowest with DBF/Arb2 (9 fragments).
Table 1—Marker type, number of markers analysed, polymorphic markers, percentage of polymorphism, PIC values and PIC% obtained in a sample of 82 sugarcane genotypes evaluated by SSR, AFLP and TRAP markers.

<table>
<thead>
<tr>
<th>Marker type</th>
<th>N markers</th>
<th>Polymorphic markers</th>
<th>% Polymorphism</th>
<th>PIC</th>
<th>PIC %</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TRAP</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DREB + Arbi 1</td>
<td>15</td>
<td>13</td>
<td>86.66</td>
<td>0.32</td>
<td>0.64</td>
</tr>
<tr>
<td>DREB + Arbi 2</td>
<td>18</td>
<td>10</td>
<td>55.55</td>
<td>0.23</td>
<td>0.46</td>
</tr>
<tr>
<td>DREB + Arbi 3</td>
<td>14</td>
<td>10</td>
<td>71.42</td>
<td>0.23</td>
<td>0.46</td>
</tr>
<tr>
<td>DBF + Arbi 1</td>
<td>18</td>
<td>15</td>
<td>83.33</td>
<td>0.21</td>
<td>0.42</td>
</tr>
<tr>
<td>DBF + Arbi 2</td>
<td>16</td>
<td>9</td>
<td>56.25</td>
<td>0.16</td>
<td>0.32</td>
</tr>
<tr>
<td>DBF + Arbi 3</td>
<td>21</td>
<td>18</td>
<td>85.71</td>
<td>0.17</td>
<td>0.34</td>
</tr>
<tr>
<td>LEA + Arbi 1</td>
<td>14</td>
<td>10</td>
<td>71.42</td>
<td>0.38</td>
<td>0.76</td>
</tr>
<tr>
<td>LEA + Arbi 2</td>
<td>16</td>
<td>13</td>
<td>81.25</td>
<td>0.32</td>
<td>0.64</td>
</tr>
<tr>
<td>LEA + Arbi 3</td>
<td>20</td>
<td>16</td>
<td>80.00</td>
<td>0.34</td>
<td>0.68</td>
</tr>
<tr>
<td>ACQUA + Arbi 1</td>
<td>21</td>
<td>15</td>
<td>71.42</td>
<td>0.40</td>
<td>0.80</td>
</tr>
<tr>
<td>ACQUA + Arbi 2</td>
<td>25</td>
<td>15</td>
<td>60.00</td>
<td>0.35</td>
<td>0.70</td>
</tr>
<tr>
<td>ACQUA + Arbi 3</td>
<td>27</td>
<td>16</td>
<td>59.25</td>
<td>0.24</td>
<td>0.48</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>225</strong></td>
<td><strong>160</strong></td>
<td><strong>%</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>18.75</strong></td>
<td><strong>13.30</strong></td>
<td><strong>71.09</strong></td>
<td><strong>0.28</strong></td>
<td><strong>0.56</strong></td>
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<tr>
<td><strong>AFLP</strong></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>E-ACT + M-CAT</td>
<td>31</td>
<td>25</td>
<td>80.60</td>
<td>0.32</td>
<td>0.64</td>
</tr>
<tr>
<td>E-ACG + M-CTT</td>
<td>32</td>
<td>25</td>
<td>78.10</td>
<td>0.32</td>
<td>0.64</td>
</tr>
<tr>
<td>E-ACG + M-CTC</td>
<td>34</td>
<td>29</td>
<td>85.30</td>
<td>0.24</td>
<td>0.48</td>
</tr>
<tr>
<td>E-ACT + M-CAG</td>
<td>40</td>
<td>30</td>
<td>75.00</td>
<td>0.26</td>
<td>0.52</td>
</tr>
<tr>
<td>E-AGA + M-CTG</td>
<td>45</td>
<td>36</td>
<td>80.00</td>
<td>0.23</td>
<td>0.46</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>182</strong></td>
<td><strong>145</strong></td>
<td><strong>%</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>36.40</strong></td>
<td><strong>29.00</strong></td>
<td><strong>79.67</strong></td>
<td><strong>0.28</strong></td>
<td><strong>0.55</strong></td>
</tr>
<tr>
<td><strong>SSR</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cir51</td>
<td>5</td>
<td>5</td>
<td>100.00</td>
<td>0.68</td>
<td>0.68</td>
</tr>
<tr>
<td>Cir56</td>
<td>5</td>
<td>5</td>
<td>100.00</td>
<td>0.71</td>
<td>0.71</td>
</tr>
<tr>
<td>Cir74</td>
<td>7</td>
<td>7</td>
<td>100.00</td>
<td>0.77</td>
<td>0.77</td>
</tr>
<tr>
<td>SMC31CUQ</td>
<td>6</td>
<td>6</td>
<td>100.00</td>
<td>0.78</td>
<td>0.78</td>
</tr>
<tr>
<td>SMC1047HA</td>
<td>15</td>
<td>15</td>
<td>100.00</td>
<td>0.86</td>
<td>0.86</td>
</tr>
<tr>
<td>SMC2017FL</td>
<td>13</td>
<td>13</td>
<td>100.00</td>
<td>0.88</td>
<td>0.88</td>
</tr>
<tr>
<td>SCA48</td>
<td>14</td>
<td>14</td>
<td>100.00</td>
<td>0.87</td>
<td>0.87</td>
</tr>
<tr>
<td>SCB100</td>
<td>12</td>
<td>12</td>
<td>100.00</td>
<td>0.90</td>
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</tr>
<tr>
<td>SCB312</td>
<td>13</td>
<td>13</td>
<td>100.00</td>
<td>0.88</td>
<td>0.88</td>
</tr>
<tr>
<td>SCC01</td>
<td>13</td>
<td>13</td>
<td>100.00</td>
<td>0.84</td>
<td>0.84</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>103</strong></td>
<td><strong>103</strong></td>
<td><strong>%</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>10.30</strong></td>
<td><strong>10.30</strong></td>
<td><strong>100.00</strong></td>
<td><strong>0.82</strong></td>
<td><strong>0.82</strong></td>
</tr>
</tbody>
</table>

The average of 13.30 polymorphic bands per primer combination was lower than that (29.38 polymorphic bands) derived with 18 TRAP primer combinations on a broad set of accessions composed of sugarcane hybrids, *Erianthus*, *Miscanthus* and *Saccharum* species as reported by Alwala *et al.* (2006). Different genotypes were evaluated in our research compared to the one conducted by Alwala *et al.* (2006), and thus the different numbers of polymorphic bands observed are probably due to differences in the genetic background of the accession group analysed. In fact, the large number of different accession types evaluated by Alwala *et al.* (2006) was wider than those of our study composed exclusively of commercial and semi-commercial varieties. The DBF/Arb 2 combination gave the lowest PIC value (0.16) while ACQUA/Arb1 combination gave the highest value (0.40). The average GS obtained among the genotypes was 0.65 with the lowest similarity value observed between IACSP03-8140 and IACSP03-8189 (0.46) and highest between IACSP03-8136 and IACSP03-8125 (0.84). The GS estimated with the 160 TRAP derived markers gave a coefficient of variation (CV) of 6.50%.
Amplification fragment length polymorphism – AFLP

The five AFLP primer combinations screened produced a total of 182 bands of which 145 (79.67%) were polymorphic. The total number of bands per primer combination ranged from 31 (E-ACG + M-CAT) to 45 (E-ACG + M-CTG) with an average of 36.4 bands. The PIC values ranged from 0.23 (E-ACT + M-CTG) to 0.32 (E-ACT + M-CAT and E-ACG + M-CTT). The average GS was 0.67 with the lowest value observed between IACSP93-2094 and IACSP03-8136 (0.38) and the highest between IACSP03-8077 and IACSP03-8145 (0.88), considering a CV of 6.5%. The average GS observed among the 82 sugarcane genotypes was lower than that of 47% (CV of 4.29%) reported by Lima et al. (2001) on 83 sugarcane varieties from different Brazilian breeding programs.

Microsatellites (SSRs)

The 10 microsatellite primers used yielded a total of 103 alleles (markers) with an average of 10.3 alleles per locus ranging from 5 (Cir51, Cir56) to 15 (1047HA). The PIC values ranged from 0.68 (Cir 51) to 0.90 (SCB100) with an average value of 0.82 (Table 1). These values were higher than those reported for 15 sugarcane commercial varieties from Coimbatore assessed with 168 SSRs (Singh et al., 2008).

The average GS among the 82 sugarcane genotypes was 0.51 with the lowest pair wise genetic similarity value observed between IAC97-2028 and IACSP03-8164 (0.28) and the highest value observed between IACSP97-7077 and IACSP97-2023 (0.87) considering a CV of 13.0%. The average GS value observed here was smaller (68.3%) than that reported among 20 sugarcane varieties assessed with SSRs (Selvi et al., 2008).

Comparison among different marker types

As expected, the results obtained with the different molecular markers used in this research were different, since each marker system allowed us to assess the genetic variability of the 82 sugarcane genotypes at different genomic regions.

In general, the polymorphism observed in this study reflects the nature of each type of marker (AFLP, TRAP, and SSRs). The PIC value adjusted for percentage (PIC%) varied according to the respective marker type: from 0.32 (DBF/ A2) to 0.80 (ACQUA/ A1) for TRAP, 0.46 (E-AGA + M-CTG) to 0.64 (E-ACT + M-CAT and E-ACG + M-CTT) for AFLP, and from 0.684 (CIR51) to 0.896 (SCB100) for SSR.

The highest PIC% values were observed with SSR markers, probably due to the nature of this marker, which usually shows high mutation rates when compared to other types of molecular markers (Jarne and Lagoda, 1996).

The estimates of the correlation between the genetic similarity matrices and its significance (t test) were generally low: \( r = 0.12 (t = 1.53 \text{ ns}, p = 0.937) \) for AFLP vs TRAP, \( r = 0.011 \) \( (t = 0.16 \text{ ns}, p = 0.565) \) for AFLP vs SSRs, and \( r = 0.24 \) \( (t = 3.62 \text{ ns}, p = 0.999) \) for TRAP vs SSRs.

This situation was expected, since each marker system reflects the polymorphism in different portions of the genome (i.e. repetitive regions, or genome wide or target genes). The highest correlation value was observed between TRAP and SSRs and this could be partially attributed to the fact that among the 10 SSRs screened, 4 were derived from expressed sequence tags (EST-SSRs) sampling a functional region of the genome.

The range of variation of GS values was smaller for TRAP (0.45–0.84) than for AFLP (0.38 –0.88) and SSR (0.28–0.87) (Figure 1). The TRAP markers used are derived from candidates genes related to drought tolerance in sugarcane. Drought tolerance has been considered as an important trait in sugarcane breeding, and probably these genes have been under a higher selection pressure than those assessed by SSR and AFLP markers. So, there is a lower genetic variability for this trait in the pool of the genotypes sampled in comparison with those revealed by the repetitive or random markers.
The highest range in the GS distribution was generated with microsatellite data. In sugarcane, SSR markers have been considered as the most efficient marker for its characterisation, due to their reproducibility and high polymorphisms (Pinto et al., 2006) and also because they are ideal to establish relationships and for fingerprinting. In this study, the SSR makers used allowed the identification of several alleles including those that are unique to a variety or clone contributing to an increase in the range in the genetic diversity in the pool of genotypes assessed.

![Frequency distribution of TRAP, AFLP and SSR-based genetic similarity values for all the 82 genotypes evaluated (3321 genotypes combinations).](image)

According to Alwala et al. (2006), AFLP markers may be more robust for detecting polymorphisms among closely related genotypes, as they are more likely to sample different segments throughout the genome. However, it has been suggested that the choice of the marker (random or functional) for germplasm characterisation is dependent on the aim of the study. If the study is focused on the evolution or historical processes, random markers are suitable (Tiendiren et al., 2002).

For the assessment of variation in wild relatives or for establishing GS between genotypes for breeding purposes, it is more valuable to have information on the variability of specific genes that potentially affect important traits in breeding. The variation in expressed or regulatory sequences might reflect the past influences of selections, which could be different for each gene.

For instance, the characteristics that enable a sugarcane variety to show superior performance in a specific environment may depend on a limited set of genes, and the variation in genes will probably not be the same as in a group of genes involved in the expression of an independent characteristic.

Therefore the variation in these genes will most probably not be detected using random markers (Tienderen et al., 2002). In fact, the importance of accessing polymorphisms that account for the phenotypic variation (i.e. in target genes) in genetic breeding has contributed to the increase in the use of single nucleotide polymorphism (SNP) marker technology for sugarcane characterisation (Cordeiro et al., 2006).

Thus, it is important to choose a marker system related to the objective of the research. Using different markers is also an interesting approach since it provides different and complementary information on genotypes.
REFERENCES


**COMPARAISON ENTRE TECHNIQUES AFLP, TRAP ET SSRSs POUR ESTIMER LA PARENTÉ GENOMIQUE CHEZ LA CANNE À SUCRE**

Par

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**MOTS-CLÉS: Marqueur Moléculaire, Distance Génétique, Canne à Sucre.**

**Résumé**

Le programme d’amélioration variétale de ‘Instituto Agronômico de Campinas’ fait l’usage routinier de différents types de marqueurs moléculaires pour la caractérisation des clones et variétés. Dans cette étude, nous avons comparé la parenté génomique parmi 82 clones/variétés de canne à sucre en utilisant trois types de marqueurs moléculaires: AFLP, TRAP et microsatellites (SSRs). Cinq combinaisons d’amorce sélective pour AFLP, 10 amorces SSRs et 4 marqueurs TRAP développés à partir des données des gènes candidats impliqués dans le métabolisme pour la résistance à la sécheresse ont été utilisées en combinaison avec trois amorces arbitraires. Les correspondances génétiques, basées sur la méthode du coefficient de Jaccard, du dendrogramme en classification ascendante et hiérarchique et la matrice de comparaison, ont été faites selon le logiciel NTSYS. Un total de 410 marqueurs polymorphes a été obtenu notamment 145 marqueurs AFLP, 103 SSRs et 160 marqueurs TRAP. Quoique l’estimation moyenne de la similarité génétique basée sur les marqueurs AFLP (0,675) et marqueurs TRAP (0,655) était plus près l’un de l’autre en comparaison avec les marqueurs SSRs (0,522), la corrélation entre les marqueurs TRAP et SSRs était plus élevée (r = 0.24). Le coefficient de variation était inférieur entre les marqueurs AFLP et TRAP (~6.55%) en comparaison avec les SSRs(13%). Ces résultats indiquent que le choix de marqueurs devrait être soigneusement considéré. En sus, le choix doit être basé sur l’objectif de l’application des marqueurs dans le programme d’amélioration variétale car il n’est pas possible d’adopter un système de marqueur pour tous les besoins pour la caractérisation du germoplasme.
COMPARACIÓN DE MARCADORES AFLP, TRAP Y SSRs EN LA EVALUACIÓN DE RELACIONES GENÉTICAS DE CAÑA DE AZÚCAR

Por

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PALABRAS CLAVE: Marcadores Moleculares, Diatancia Genética, Caña de Azúcar.

Resumen

El PROGRAMA de Fitomejoramiento de la Caña de Azúcar de Campinas ha utilizado de manera rutinaria diferentes tipos de marcadores moleculares para la caracterización de sus clonas mejoradas y variedades. En el presente trabajo, comparamos las relaciones genéticas entre 82 clonas/variedades de caña de azúcar usando tres tipos de marcadores moleculares: AFLP, TRAP y Microsatélites (SSR). Cinco combinaciones de iniciadores selectivos AFLP, diez SSR y cuatro iniciadores fijos TRAP fueron diseñados a partir de genes candidatos involucrados en el metabolismo de respuesta en la tolerancia a la sequía, usándoseles en combinación con tres iniciadores arbitrarios. La similitud genética basada en el coeficiente de Jaccard, el dendrograma y la comparación de matriz fueron calculados usando el programa de cómputo NTSYS. Se obtuvieron un total de 410 marcadores polimórficos: 145 AFLPs, 103 SSRs y 160 TRAP. Pese a que el promedio de los cálculos de similitud genética se sustentaron en la relación entre los marcadores AFLP (0.675) y TRAP (0.655), más cercana entre ellos que en relación a los SSRs (0.522), la correlación entre TRAP y SSR fue mayor ($r = 0.24$). El coeficiente de variación fue menor para AFLP y TRAP ($~6.55\%$) que para los SSR (13%). Estos resultados indican que la elección de marcadores moleculares debe conducirse juiciosamente dependiendo del propósito para aplicarles en un programa de fitomejoramiento, ya que no es posible seleccionar un sistema de marcadores que cumpla con todos los requerimientos en la caracterización de germoplasma.
A REVIEW OF EXISTING REGULATIONS FOR GM CROPS
AND PROGRESS MADE ON GM SUGARCANE
RESEARCH IN CHINA

By

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KEYWORDS: Regulations, GM Crops, GM Sugarcane, China.

Abstract
In China, legislation is in place and a system has been established for the safety assessment of genetically modified organisms (GMOs). The Ministry of Agriculture is responsible for the regulation of genetically modified (GM) crops and a Biosafety Committee has been authorised to handle the safety evaluation for such crops. A set of regulations for GM crops has also been promulgated. Good progress has been made in GMO development in the laboratories, but so far no GM sugarcane has reached commercial testing. A number of standard protocols for the detection of GM crops and their derived products have been developed and one for detecting GM sugarcane is currently being formulated.

Introduction
China is one of the countries that grows genetically modified (GM) crops in the world. There are five GM crops presently cultivated in China namely tomato, pepper, poplar, papaya and cotton (Wang et al., 2007). In 2006, GM cotton was the leading crop being grown over 3.5 million hectares and covering up two thirds of the total cotton planting area. With the fast adoption of GM crops, China is also developing biosafety measures to ensure their safe use. A system has been established for the assessment of GM crops and legislation is also in place for their control. The Ministry of Agriculture is responsible for the regulation of GM crops and for agricultural products derived from them. A Biosafety Committee, to oversee agricultural GMOs, is authorised to handle the safety evaluation for all greenhouse experiments, environmental impacts, release, and commercial production. A set of regulations for GM crops, animals and microbes has also been promulgated. In this paper, a review of the various biosafety measures in place in China as well as progress achieved in the development of GM sugarcane is reported.

Regulations for GM crops in China
China has issued a set of regulations for GM crops, animals and microbes. In 1993, the first regulation for the administration of genetic engineering was promulgated by the State Scientific and Technological Commission. Thereafter, more regulations were formulated and five major ones for agriculture were further promulgated by the Chinese State Council (Anon., 2001) and Ministry of Agriculture (Anon., 2002).

The State Council, well ahead of the entry into force of the Cartagena Protocol on Biosafety in 2003, promulgated a primary regulation entitled ‘Regulations on Administration of Agricultural Genetically Modified Organisms Safety’ in May 2001 (Anon., 2001). This regulation caters for the control of GM plants, animals and microbes with the objectives to protect human health and the
environment. The regulation which contains 56 articles also aims to strengthen control on genetic engineering research and development (R&D), as well as production, processing and trading of GM agricultural products, including plants, animals and microbes. It calls for mandatory assessment of the safety of all GM products being developed as well as for labelling of such products. Research institutions are required to have facilities and techniques to ensure the safety of their research on GMOs. Research institutions developing GMOs, upon completion of experiments, need to apply for a Safety Certificate from the State Agriculture Administration Department (SAAD) for their final product. An individual engaged in the production and processing of GM products must also have the approval from the SAAD or from the provincial level. Products listed and authorised in the GM Product Catalog in China must be properly labelled before they are marketed. The SAAD is also responsible for approving the import of GMOs and GM products while the Entry-Exit Inspection and Quarantine Bureaus are responsible for their export. The SAAD also has the power to ban any production, processing or trading of GM product that is found to be a hazard to human health, and the environment.

**Procedures in safety assessment of GM sugarcane**

Article 2 of the ‘Regulations on Administration of Agricultural Genetically Modified Organisms Safety’ developed by the State Council describes the procedures for the assessment of GM crops related to research, restricted field-testing, medium-scale field-testing and productive testing. Restricted field-testing concerns small-scale tests conducted within a controlled system or under controlled conditions. For GM sugarcane, such experiments can be conducted in a contained greenhouse. Medium-scale field-testing can be carried out under natural environmental conditions with appropriate safety measures. The field should be fenced and, in the case of GM sugarcane being tested, no other sugarcane plantations should be present within a distance of 300 metres for non-flowering varieties and 500 metres for flowering varieties, the isolation distance being based on other crop species (Anon., 2002). Productive testing consists of large-scale tests prior to commercial production and application. When an experiment has passed one testing stage and requires testing in the next stage, a new application must be made to the SAAD. If the tests pass the safety evaluations conducted by the Biosafety Committee and a Safety Certificate is obtained, the SAAD may give its approval. Research on GMOs in China conducted by Chinese-foreign contractual cooperation or joint capital or sole foreign capital must have the approval from the competent Agricultural Administrative Department of the State Council.

Four additional regulations, based on the primary regulation by the State Council, concerning safety assessment (Anon., 2002), labelling, processing, and import and export of agricultural products have also been promulgated by the Ministry of Agriculture.

**Gene cloning for genetic modification of sugarcane**

Apart from the genes obtained from abroad for sugarcane transformation including the galanthus nivalis agglutinin (GNA) gene from the snowdrop lily (Chen et al., 2004a) and Hsi pro-1 gene (Chen et al., 2004b) for pest resistance, as well as the leafy (Li et al., 2003) gene for plant flowering, Chinese scientists have cloned a few genes. In 2000, a trehalose synthase gene (Tsase) was cloned using RT-PCR based on the sequence of a trehalose synthase gene from the Basidiomycete, Grifola frondosa, and the sequence of 2199 bp containing a start codon and a stop codon was transformed into sugarcane (Zhang et al., 2000). A few genes were cloned from the coat protein gene and the N1b coding region of Sugarcane mosaic virus (ScMV), namely ScMV-CP-E (Jiang et al., 2006), ScMV-HC-Pro (Liu, 2008), SrMVP1 and Nib (Yao et al., 2006a). ScMV-CP-E
is a gene from ScMV-CP and a specific inhibitor to strain E of ScMV. The ScMV-HC-Pro and SrMVP1 genes are factors in RNA-mediated silencing in viruses. The *Nib* gene contains the consensus motif GDD box to resist the virus. The templates to clone the above genes and their pathways are different but they all aim at inhibiting expression of ScMV. In addition, a gene from *Sugarcane yellow leaf virus* coat-protein (ScYLV-CP) was cloned and a ScYLV-CP prokaryotic expression vector was constructed to evaluate the gene’s function (Huang et al., 2007). Furthermore, a full-length cDNA library was constructed from a water-stressed plant of *Erianthus arundinaceus* in order to isolate genes for drought tolerance (Liu and Zhang 2008; Cai et al., 2009). For the improvement of sugarcane, the gene BADH (encoding betaine aldehyde dehydrogenase) for drought tolerance (Yu, 2004), and a new promoter Prd29A (Wu et al., 2008) were cloned from *Arabidopsis thaliana*. A gene coding for sucrose phosphate synthase (He et al., 2007) was also cloned from sugarcane and the sequence was analysed. Another gene, resveratrol synthase (RS) from grape was transferred into sugarcane for value-added products (Xu et al., 2008b). RS is one of the key enzymes in resveratrol biosynthesis, which catalyses one molecule of coumaroyl CoA and three molecules of malonyl CoA to form one molecule of resveratrol.

**Leading method in sugarcane gene transformation**

At the start, sugarcane transformation was mediated by *Agrobacterium tumefaciens* strain LBA4404 (Chen et al., 1996). Another strain EHA105 was found suitable for gene transfer into sugarcane (Zhang et al., 2006). Thereafter, particle bombardment, a direct DNA transforming system suitable for the transformation of monocots, has been used for transformation of sugarcane. This system can transfer minimal gene expression cassettes (promoter, open reading frame, terminator) into plant genomes and also generates safer transformants, in addition to multiple genes delivery. Direct gene transfer now prevails over *Agrobacterium tumefaciens* and is a major approach for gene transfer into sugarcane calli (Chen and Chen, 2004). Almost all existing GM sugarcane lines so far developed in China are as a result of particle bombardment except for one event (Zhang et al., 2000). However, some disadvantages of using the particle bombardment system have been observed. A large population of GM sugarcane plants needs to be screened in order to identify a desirable line, resulting in huge screening costs. Hence, the use of *Agrobacterium tumefaciens* for gene transfer into sugarcane is being reevaluated.

**Progress on GM sugarcane research**

China has made good progress at the laboratory level on the development of GM sugarcane. The gene *Tsase* was transformed into sugarcane by *Agrobacterium tumefaciens* strain EHA105 in 2000 (Zhang et al., 2000). This gene produces trehalose, a healthy sugar that could be a substitute for sucrose. Three transgenic plants were confirmed by PCR and Dot-Southern blot analysis and are in the stage of restricted field-testing. The transgenic plants are also promising drought-tolerant clones.

Insect pests can cause significant yield losses in sugarcane. In 2004, genes of *GNA* for aphid-resistance and *Hs1 pro-1* for nematode-resistance were introduced into sugarcane calli via particle bombardment and transgenic plants were obtained and tested in the greenhouse. Sugarcane transgenic lines with cry1A(c) gene were obtained in 2008 following particle bombardment and an application has been made for restricted field testing (Xu et al., 2008a). The cloning of the coat protein genes of *Sugarcane mosaic virus* (ScMV) was initiated in 2004 and several groups were involved (Yao et al., 2004, 2006; Guo et al., 2008). More than four genes including ScMV-CP-E, ScMV-HC-Pro, SrMVP1, and *Nib* have been cloned and transformed in variety Badila and hybrid
clones. A few GM plants with SCMV-CP-E are now ready for productive testing. A cloned BADH gene for drought tolerance and a new promoter Prd29A from *Arabidopsis thaliana* were transferred into sugarcane callus tissue by particle bombardment. A number of experiments are currently being performed at laboratory and field level for the development of GM sugarcane.

**Standards for detection of GM sugarcane**

A number of standards have been promulgated in China for the detection of GM crops including maize, rapeseed, soybean, potato, cotton, tobacco, tomato and rice and their derived products. These standards provide guidelines for detecting the GM component and for the biosafety assessment of the GM crops and their derivates. However, no standard for detection of GM sugarcane has been developed so far. The Ministry of Agriculture is presently working on a Standard for the detection of GM sugarcane and its derived products.

**Conclusion**

The development of GMOs has progressed extensively in the laboratory in China. Emphasis is also on biosafety measures to ensure the safe use of the GMOs due to the increasing demand from farmers to exploit such crops. It is expected that GM sugarcane will be one of the leading GM crops in the future in view of its specific characteristics for adaptation to less productive lands and due to its non flowering nature in mainland China, thus representing low biosafety issues.

**Acknowledgement**

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UNE REVUE DES LÉGISLATIONS EXISTANTES POUR LA BIOSÉCURITÉ DES PLANTES GÉNÉTIQUEMENT TRANSFORMÉES ET LE PROGRÈS DE LA RECHERCHE EN CANNE À SUCRE GÉNÉTIQUEMENT MODIFIÉE EN CHINE

Par

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MOTS-CLÉS: Règlements, Plantes Génétiquement Modifiées, Canne à Sucre Transgénique, Chine.

Résumé
LA LÉGISLATION étant en place, un système a été établi en Chine pour évaluer les risques associés avec les organismes génétiquement modifiés (OGMs). Il incombe au Ministère de l’Agriculture de réglementer les plantes génétiquement modifiées (GM) et un Comité pour la biosécurité est autorisé à évaluer les risques associés avec les plantes GM. Un nombre de règlements pour les plantes GM a été promulgué. Ainsi, des progrès conséquents ont été accomplis dans la production des OGMs au laboratoire, mais jusqu’ici aucune canne transgénique n’a atteint l’étape d’évaluation commerciale. Un certain nombre de protocoles standard pour la détection des OGMs et leurs produits dérivés ont été développés. En sus, un protocole est actuellement en préparation pour la canne transgénique.

UNA REVISIÓN DE REGULACIONES ACTUALES PARA LOS CULTIVOS GM Y AVANCES EN LA INVESTIGACIÓN DE CAÑA DE AZÚCAR EN CHINA

Por

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PALABRAS CLAVE: Regulaciones, Cultivos GM, Caña de Azúcar GM, China

Resumen
EN CHINA, existen un marco legal y un sistema establecido para la evaluación de seguridad de organismos genéticamente modificados (OGMs). El Ministerio de Agricultura es responsable de la regulación de cultivos genéticamente modificados (GM) y un Comité de Bioseguridad ha sido autorizado para conducir la evaluación de seguridad para tales cultivos. Asimismo, un conjunto de regulaciones para los cultivos GM ha sido promulgado. Un buen avance ha sido conseguido en el desarrollo de GMO en los laboratorios, pero al momento ninguna caña de azúcar GM ha alcanzado una evaluación comercial. Se ha desarrollado un número de protocolos estándar para la detección de cultivos GM y de sus productos derivados, y actualmente existe uno definiéndose para la detección de caña de azúcar GM.
A SUPPORT FRAMEWORK FOR DEPLOYMENT OF GENETICALLY MODIFIED SUGARCANE: IDENTIFYING POTENTIAL RISKS FROM SEXUAL REPRODUCTION OF COMMERCIAL CULTIVARS

By

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KEYWORDS: Sugarcane, Genetic Modification, Biotechnology, Regulation, Deployment, Sexual Reproduction.

Abstract
GLOBAL investments in developing genetically modified (GM) sugarcane (\textit{Saccharum} spp. hybrids) to enhance its agronomic performance generate novel bioproducts, and bio-industries based on the crop's attributes for high biomass production are increasing. As for all GM crops, GM sugarcane will have to go through regulatory systems prior to commercial release, which will encompass environmental safety assessments. However, sexual reproduction for the vegetatively propagated crop has not been studied except to improve breeding. Consequently, knowledge of sexual reproduction in a commercial production setting is lacking and, thus, the baseline to determine possible environmental effects of a GM sugarcane is non-existent. We have initiated research in Australia to close this historical and global knowledge gap for sugarcane to provide baseline information for determining any potential environmental risks and, if necessary, for developing risk management strategies for the deployment of GM sugarcane. A proposed research framework developed and refined for identifying and addressing risks arising from potential sexual reproductive avenues of non-intentional gene escape from a GM sugarcane crop is described. We have engaged Australian regulatory authorities frequently during the development of the framework and the subsequent research to address the important issues for which they consider there is insufficient information. The principles and approaches described in the research framework would be equally applicable for assessing potential issues for the deployment of GM sugarcane in other agro-environments and for future developments of novel GM grass crops.

Introduction
Increasingly, global investments are aimed at the development of GM sugarcane (\textit{Saccharum} spp. hybrid) germplasm. Traits to improve the sugarcane business agronomically and those that will expand the crop's scope of agro-industrial end-uses are being targeted. During the development and prior to the release of GM sugarcane, regulatory systems in many jurisdictions will encompass rigorous, science-based environmental safety assessments. Initially, the potential routes of transgene escape and establishment (within and outside cultivation) for the environment
receiving the GM sugarcane require identification. Future evaluations of environmental effects of individual transgenes can then be conducted and compared from such generic baseline.

Relative to the abundance of agronomical and environmental studies on factors affecting growth and development of the vegetatively-propagated crop, sugarcane sexual reproduction has been globally and historically ignored except by breeders. Kock (2007) highlighted the lack of any sugarcane-derived data in a presentation on biosafety regulation of GM crops as no data for cane existed in the scientific literature at that time. Such a situation was noted by Bonnett et al. (2007) in the context of a potential introduction of GM sugarcane, which would initially be addressed by conducting studies for an understanding of the crop’s sexual reproduction. Sugarcane seed holds no caloric or economic importance in the harvested product. In most other crops, flowering is a pre-requisite to obtaining the harvestable product, seeds. In sugarcane, flowering is not required to obtain the next filial generation nor economic yield. Consequently, there are no studies on the reproduction of sugarcane in the field let alone gene dispersal via pollen or seed. For other grass crops, where the production of seed for planting material needs to be of high genetic purity and quality, the isolation distances of genotypes have been determined. Further, the absence of flowering of sugarcane in some areas has been used to assert sugarcane is a ‘secure biofactory’ (Wang et al., 2005); indeed, an untested assumption in many sugarcane growing regions. Finally, while sugarcane is unlikely to pose any new risk not evaluated for other transgenic crops, the necessary data are not available for sugarcane. Hence, a comprehensive understanding of the sexual reproductive biology and ecology of sugarcane is required to provide baseline information for the decision-making process of regulatory authorities to manage the safe release of GM sugarcane.

Elements in risk assessments

Within regulatory systems, the assessment of environmental risks for the approval and management of GM crops involves (Craig et al., 2008): a) the identification of potential environmental effects or perceived hazards that would arise from its release; b) an evaluation of the potential consequences; and, c) the determination of the probability (likelihood) of their occurrence.

Identifying potential environmental effects or hazards is generally based on biological features of the modified species/crop, and is dependent on the ecological context in which it is proposed for release. The general focus is on the potential for: a) unintentional escape of the GM organisms that would, if unmanaged, elicit a detrimental effect to the environment; and, b) transfer of the transgene(s), and thus those trait(s), to sexually compatible species (or to non-GM cultivars from GM crops) that would affect their fitness, alter their role in various environmental niches or facilitate the introgression to other non-targeted genetic pools.

Determining the likelihood of an environmental effect or hazard to occur would define the level of exposure to the environment. Once effects or hazards have been identified for a target environment, the competent authority within regulatory systems would assess any consequence of the particular transgenes in relation to any such hazard. While the evaluation of the consequences (for that effect or hazard to occur) is a process largely dependent on the specificity of the genes/traits modified, it is possible to generate a generic research framework to identify the effect or hazard component of risk assessment.

Development of a research framework

A conceptual framework to identify the environmental effect or hazard component of environmental risk is shown in Figure 1. The generic inquiries start with the most basic sexual reproductive process, flowering, and ends with seed germination and establishment of new plants in the target environment(s). Depending on the answers to the questions sequentially asked, the researcher is directed to more research. Should the process under study give rise to no potential effect or hazard, the information gathering can cease. For any particular transgene, a risk analysis would encompass additional analyses to verify if any biological parameter changed as a result of genetic improvement and, thus, if there are potential effects or hazards to be addressed. A risk
analysis would then be prepared by the competent authority based on the data, methods, reproducibility, likelihood and relevance of the effect, with a subsequent preparation of a risk management strategy to mitigate or manage any risk.

Fig. 1—A generic framework for the identification of potential environmental effects or hazards within a risk assessment, resulting from the sexual reproduction of sugarcane in commercial fields.

An important feature of the process of developing and refining this research framework has been regular engagement with Australian regulatory agencies during the planning and conduct of the research. This has ensured that their most important questions are being addressed, allowing us to modify both the strategy and experimental approaches as a consequence of feedback. With the publication of results as a final objective, this would allow: (i) the work to be available to a wider audience including regulators and technology developers; and, (ii) other researchers to apply it to their agro-environments of interest, and to identify any omission for their particular situation in order for them to design experiments that would fill those knowledge gaps. The subsequent sections summarise the results we have found when developing and applying the framework to sugarcane growing regions in Australia.

Does sugarcane flower in the target environment(s)?

Flowering varies greatly between years and locations (Berding et al., 2004). In some instances, such observations have led to the location of breeding facilities in areas of highest flowering. They have also led, in areas of no or low flowering, to the notion that sugarcane is an ideal GM crop because it is vegetatively propagated and does not flower. However, prior to the release of GM crops, a determination of whether flowering occurs is crucial and, if it does, if any viable seed is produced. As sugarcane is grown over a range of latitudes and altitudes (even in one country), multiple environments should be monitored. In Australia, sugarcane is grown from
latitude 16ºS in the north to 29ºS in the south, with flowering varying across seasons and cropping regions (Cox et al., 2000). Our approach has been to monitor the flowering of sugarcane in commercial fields in several regions in north Queensland over several years; multiple sites within each region were monitored at monthly intervals. Flowering occurred to some degree in all regions in all years studied, with the peaks of flowering for cropping seasons 2007 and 2008 in the Mulgrave and Herbert River regions shown in Table 1. Additionally, we also have quantified the extent of flowering in other sugarcane growing regions at higher latitudes. Flowering, as expected, was less frequent and less intense.

Table 1—Time of highest flowering of sugarcane cultivars (Saccharum spp. hybrids) and of Saccharum spontaneum L. in the Mulgrave and Herbert River regions of north Queensland, Australia, seasons 2007 and 2008.

<table>
<thead>
<tr>
<th>Region</th>
<th>Month</th>
<th>Saccharum spontaneum</th>
<th>Sugarcane hybrids</th>
<th>Saccharum spontaneum</th>
<th>Sugarcane hybrids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mulgrave</td>
<td>March</td>
<td>7.34 (4.90)</td>
<td>39.2 (23.4)</td>
<td>48.6 (25.1)</td>
<td>29.5 (36.4)</td>
</tr>
<tr>
<td></td>
<td>April</td>
<td>39.2 (23.4)</td>
<td></td>
<td>48.6 (25.1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>June</td>
<td>48.6 (25.1)</td>
<td></td>
<td>29.5 (36.4)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>July</td>
<td>29.5 (36.4)</td>
<td></td>
<td>48.6 (25.1)</td>
<td></td>
</tr>
<tr>
<td>Herbert</td>
<td>June</td>
<td>44.9 (34.5)</td>
<td>45.7 (34.6)</td>
<td>61.5 (40.1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>July</td>
<td>64.8 (38.8)</td>
<td></td>
<td>61.5 (40.1)</td>
<td></td>
</tr>
</tbody>
</table>

Note: The data represent the mean proportion of flowering stalks of replicates assessed in different locations across the season (S.D., standard deviation). The data shown is the maximum value observed across the season for the wild relative and the crop.

Number of assessed thickets/paddocks = A, 30; B, 46; C, 32; D, 46; E, 23; F, 26; G, 25; H, 17.

Are there any sexually compatible species to sugarcane?

Sugarcane and its closest relatives are not native in many sugarcane growing countries. A good source of information for identifying species and genera present in such different countries and regions are botanical flora and herbarium specimens. Internationally published flora compendia and taxonomical atlases are other valuable sources. In some instances, details of the occurrence and locations of plants related to sugarcane can be found in work describing the collection of germplasm for breeding purposes either indigenous (e.g., Nagatomi and Degi, 2007) or endo-exogenous (viz., regional or world germplasm repositories: Sugarcane Breeding Institute Collection, Coimbatore, India; Sugarcane Development Program, Canal Point, USA).

From breeding literature, we identified a list of species that were demonstrated to produce fertile hybrids with commercial sugarcane (Bonnett et al., 2008). When comparing these with related species and genera present in such different countries and regions are botanical flora and herbarium specimens. Internationally published flora compendia and taxonomical atlases are other valuable sources. In some instances, details of the occurrence and locations of plants related to sugarcane can be found in work describing the collection of germplasm for breeding purposes either indigenous (e.g., Nagatomi and Degi, 2007) or endo-exogenous (viz., regional or world germplasm repositories: Sugarcane Breeding Institute Collection, Coimbatore, India; Sugarcane Development Program, Canal Point, USA).

From breeding literature, we identified a list of species that were demonstrated to produce fertile hybrids with commercial sugarcane (Bonnett et al., 2008). When comparing these with related species and genera present in the likely target environments of Australia for the future introduction of GM sugarcane, we identified that Saccharum spontaneum L. is the most likely species which could spontaneously hybridise with commercial sugarcane. A wild relative (and one of the progenitors) of modern sugarcane cultivars, S. spontaneum has established as naturalised populations in close proximity to commercial sugarcane in five recently recorded locations in north Queensland (Bonnett et al., 2008), in addition to one remote location on the Daly River in the Northern Territory, where no sugarcane is commercially grown. While the north Queensland populations were identified from herbarium samples and local knowledge, we determined their extent by conducting land and river surveys. For the Northern Territory location, there were entries of S. spontaneum at the Queensland Herbarium. In countries where the progenitors and relatives of sugarcane occur sympatrically with sugarcane, the most important question is whether their flowering is synchronous with commercial sugarcane. A risk assessment, thus, would focus more on the consequence of the gene being transferred rather than the likelihood of transfer per se.

Is flowering sympatric with sexually compatible species?
Flowering times and seed production of commercial crops and of the naturalised populations of *S. spontaneum* were assessed as components of the regional monitoring previously described. The monthly observations indicated that there was synchronous flowering at some locations (Olivares-Villegas *et al.*, 2008). From an analysis of seed collected from the crop and the non-domesticated species (Table 2), we demonstrated that in some instances of synchronous flowering (Table 1), both were sexually fertile and produced viable seed. Thus, in those locations there appears to be an opportunity for hybridisation between commercial sugarcane cultivars and *S. spontaneum*. Consequently, managed experiments have been conducted to determine the ability of some of the naturalised populations of *S. spontaneum* to accept pollen from commercial sugarcane.

Hybrid incidence is being assessed via non-radioactive molecular markers.

### Table 2—Seed viability peaks of sugarcane cultivars (*Saccharum* spp. hybrids) and of *Saccharum spontaneum* L. in the Mulgrave and Herbert River regions of north Queensland, Australia, during seasons 2007 and 2008.

<table>
<thead>
<tr>
<th>Region</th>
<th>Month</th>
<th><em>Saccharum spontaneum</em></th>
<th>Sugarcane hybrids</th>
<th><em>Saccharum spontaneum</em></th>
<th>Sugarcane hybrids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mulgrave</td>
<td>March</td>
<td>7.11 (4.27)</td>
<td></td>
<td>7.11 (4.27)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>June</td>
<td>7.68 (13.3)</td>
<td></td>
<td>53.0 (61.6)</td>
<td>103.8 (91.8)</td>
</tr>
<tr>
<td></td>
<td>July</td>
<td>53.0 (61.6)</td>
<td></td>
<td>86.9 (122.1)</td>
<td></td>
</tr>
<tr>
<td>Herbert</td>
<td>May</td>
<td>79.4 (115.9)</td>
<td></td>
<td>79.4 (115.9)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>June</td>
<td>14.5 (31.7)</td>
<td></td>
<td>14.5 (31.7)</td>
<td></td>
</tr>
</tbody>
</table>

Note: Data are highest mean (from collections across the season) of (triplicated) seedlings germinating per gram at the constant, optimum germination temperature of 36°C, in controlled chambers. Data shown is the maximum value observed across the season (standard deviation, S.D.). No viable seed was recorded in Herbert River region for sugarcane hybrids in 2008.

Number of assessed thickets/paddocks: A, 3; B, 14; C, 22; D, 18; E, 27; F, 16; G, 23.

### Is flowering sympatric between sugarcane cultivars?

As sympatric, synchronous sexual fertility is mostly observed in commercial cultivars across the monitored regions (Olivares-Villegas *et al.*, 2008, Table 1), we have been evaluating the potential hybridisation among sugarcane cultivars under field conditions. Distance of pollen dispersal and studies on non-intentional, inter-cultivar hybridisation have also been conducted to determine the limits of gene transfer via the microgametophyte to other *Saccharum* spp. hybrids. Such information would establish a comparative baseline for gene escape during testing phases of GM cane crops, which may be dependent on the transformed germplasm and transgene involved.

### Is fertile seed produced?

Transgene dispersal and establishment outside of cultivation via seed is one of the main environmental risk issues within the regulatory assessment for the prospective release of GM crops. While sugarcane is a vegetatively-propagated crop, under certain conditions it can produce seed — the basis of sugarcane breeding programs. As previously noted, our monitoring of north Queensland regions included seed collection not only of *S. spontaneum*, but also of sugarcane cultivars. As flowering is not indicative of the plant's ability to produce fertile seed, we tested the seed viability. Initial observations of variable seed fertility in opportunistic collections (Bonnett *et al.*, 2007) led to systematic assessments, where sub-samples of collected seed were subjected to *in vitro* germination tests. Viable seed was produced to some extent in some regions in each year when tested under the optimum germination temperature of 36°C (constant). The highest germinations of seed for 2007 and 2008 in the Mulgrave and Herbert regions are shown in Table 2. While the data is mostly lower than the average seed germination from breeders' crosses for sugarcane (*viz.*, 39 seedlings per gram of fuzz), seed germinates; thus, a risk assessment would have to consider its impact on the target...
environment. However, flowering may not always lead to viable seed set, either due to mega- or microgametophyte infertility resulting from genetic aberration and thermosensitivity.

**Can seed germinate and establish in the target environment(s)?**

Seed germination under *in vitro* ideal conditions is not indicative of seed’s ability to germinate *in situ* (viz., under the environmental conditions and niches to which the seed would be exposed). Although there is an information void on sugarcane seed longevity under field conditions and its response to environmental variables, there are some instances where there have been observations of in-field seedling establishment from germinated sugarcane seed, by sugarcane industry personnel. Albeit infrequent, there is potential for these plants to survive until sexual maturity, a fact yet to be verified as those observations were not systematically continued (to see if seedlings progressed to mature sugarcane plants). Currently, we are conducting studies on the potential of seeds and seedlings to germinate and establish, respectively, in various target environments where germination has been observed in the past, and their development (through time) is being followed.

We have also determined the response of sugarcane seed to temperature upon testing both seed produced by breeders and that collected from commercial fields under conditions of non-limiting moisture. We found that the optimum germination occurred between 30–36°C, with a 60% reduction at 24°C and a further reduction of 50% at 18°C, while there was some seed germinating at 15°C and, none was observed at 10°C (Powell et al., in preparation). Thus, temperature *per se* might not prevent germination of viable seed in sugarcane growing regions of Australia. As temperature is not the sole factor that determines germination in the environment, experiments are underway to understand the effects of various moisture stresses on sugarcane seed germination.

**Further research to support decision making on environmental issues by regulators**

Evolution of increased weediness is a potential, significant environmental consequence of non-intentional gene flow from cultivated plants to wild relatives (Ellstrand et al., 1999). Plant ecologists and population geneticists have studied such gene flow in the context of conventionally-improved crops to anticipate possible risks of transgenic crops. The most discussed resulting effects from crop-to-wild hybridisation is increased fitness through introgression, the evolution of increased weediness or invasiveness in wild relatives, the evolution of pests that are resistant to new strategies for their control, and the impacts on non-target species in associated ecosystems (Dale et al., 2002).

In sugarcane, the centuries-old agricultural practice has been to select against weedy traits in the vegetatively propagated crop, but there are wild relatives of sugarcane that are weeds (Anon., 2008). In particular, some genotypes/accessions of *S. spontaneum* are aggressive weeds in regions of southeast Asia, Indonesia, the Philippines and, recently, in Panama (Holm et al., 1997; Hammond, 1999); whether environmentally influenced or not, those accessions have particular allele combinations that could explain their resistance to environmental stresses, seed dispersal, vigorous tillering and fast developing rhizomatous root system. In Australia, the naturalised populations of *S. spontaneum* have not become as invasive, but such potential could be latent. Current studies are being conducted to understand those biological and ecological features that could explain the invasiveness of the weedy accession in Panama. A non-intentional elicitation of weediness through the modification of certain traits, such as those conferring abiotic stress tolerance, might potentially become an important issue to monitor in future developments of GM cane.

**Conclusions**

We have described a research framework for identifying and addressing risks related to potential avenues of non-intentional gene escape from a GM sugarcane crop, providing information that would aid decisions for GM cane management. While the framework was conceived for the cropping context of sugarcane growing in Australia and for assisting decision-making within its
regulatory system, it is applicable to other cane-growing industries across the world, particularly where those jurisdictions have legislation based on science-based evaluations (e.g., following legislation adherent to international standards). In addition to its application to other sugarcane agro-environments, the approaches also could be applied to other grass crops potentially useful for biofuel or bioproducts applications where sexual reproduction is not a pre-requisite for economic yield and so may be relatively unknown. The intent of this research was not to address the specific effects of particular genes, but to provide information about generic elements when potentially introducing a GM sugarcane into the environment. The research should, however, address decisions for the development and managed deployment of GM sugarcane.

Acknowledgments

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UN CADRE POUR L’EXPLOITATION DE LA CANNE À SUCRE GÉNÉTIQUEMENT MODIFIÉE: IDENTIFICATION DES RISQUES POTENTIELS DE LA RÉPRODUCTION SEXUÉE DES CULTIVARS INDUSTRIELS

Par

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MOTS-CLÉS: Canne à Sucre, Modification Génétique, Biotechnologie, Réglementation, Déploiement, Reproduction Sexuée.

Résumé

Les investissements à travers le monde sont en progression pour le développement de la canne à sucre (hybrides de Saccharum spp.) génétiquement modifiée (GM) dans le but d’améliorer sa performance agronomique pour générer de nouveaux bioproduits et pour l’utiliser comme bio-industrie grâce à sa production de biomasse élevée. Comme pour toutes les cultures GM, la canne GM aura à se conformer à des systèmes réglementaires, comprenant des évaluations de biosécurité à l’environnement avant son exploitation industrielle. Cependant, la reproduction sexuée de cette culture qui est propagée de manière végétative, n’a pas encore été étudiée, sauf pour les besoins d’amélioration génétique. Conséquemment, une connaissance dans un milieu de production industrielle n’est pas disponible et cela justifie l’obtention des données de base pour évaluer des éventuels effets environnementaux de la canne GM. Nous avons initié une recherche en Australie pour combler cette lacune historique et mondiale pour la canne à sucre. Cette étude consistait à obtenir des informations de base pour déterminer les éventuels risques à l’environnement, et si nécessaire, développer des stratégies de gestion appropriées pour l’exploitation de la canne à sucre GM. Un cadre de recherche développé et raffiné pour identifier et adresser les risques découlant des avenues potentielles de la reproduction sexuée liée à des fuites non-intentionnées des gènes de la canne GM est rapporté. Nous avons engagé les autorités régulatrices australiennes pendant le développement de ce cadre et pour la recherche subséquente pour adresser les aspects importants pour lesquels elles considéraient ne pas détenir suffisamment d’information. Les principes et les approches décrits dans ce cadre de recherche s’appliqueraient aussi pour évaluer les questions potentielles pour l’exploitation de la canne GM dans d’autres agro-environnements et pour le développement futur des nouvelles cultures herbacées génétiquement modifiées.
UNA INFRAESTRUCTURA PARA APOYAR LA LIBERACIÓN DE LA CAÑA DE AZÚCAR GENÉTICAMENTE MODIFICADA: IDENTIFICANDO RIESGOS POTENCIALES DERIVADOS DE LA REPRODUCCIÓN SEXUAL DE CULTIVARES COMERCIALES

Por
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PALABRAS CLAVE: Caña de Azúcar, Modificación Genética, Biotecnología, Regulación, Liberación, Reproducción Sexual.

Resumen
Inversiones mundiales están en incremento para desarrollar caña de azúcar (híbridos de Saccharum spp.) genéticamente modificada (GM) a fin de aumentar su desempeño agronómico, generar novedosos bioproductos y explotar bioindustrias sustentadas en los atributos del cultivo para producir gran biomasa. Al igual que para todos los cultivos GM y previo a su liberación comercial, la caña de azúcar GM tendrá que cursar sistemas de regulación entre cuyas evaluaciones a conducir se encuentra la seguridad ambiental. Sin embargo, para el cultivo propagado vegetativamente, su reproducción sexual no ha sido estudiada excepto para progresar el fitomejoramiento. En consecuencia, falta la comprensión de la reproducción sexual en un contexto de producción comercial y, por tanto, resulta inexistente el referente para determinar posibles efectos ambientales de una caña de azúcar GM. Iniciamos investigaciones en Australia para cerrar esta brecha histórica y mundial a fin de proveer información referencial para determinar cualesquier riesgos potenciales al ambiente y, de ser necesario, para desarrollar estrategias de manejo de riesgo en la liberación de caña de azúcar GM. Proponemos y describimos una infraestructura de investigación desarrollada y afinada para identificar y atender riesgos derivados de las potenciales avenidas reproductivas sexuales de escape génico no intencional desde un cultivo de caña de azúcar GM. Hemos involucrado frecuentemente a las autoridades regulatorias Australianas durante el desarrollo de la infraestructura e investigación subsecuente a fin de atender las cuestiones más importantes para los cuales consideraron que no existe información suficiente. Los principios y enfoques descritos en la infraestructura de investigación son aplicables, igualmente, a la evaluación de asuntos potenciales en la liberación de caña de azúcar GM en otros agro-ambientes y para desarrollos futuros de cultivos de pastos GM.
FUNCTIONAL GENOMICS APPROACHES FOR THE STUDY OF WATER STRESS IN SUGARCANE

By

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KEYWORDS: Water Restriction, Differential Expression, Stress Response, Drought Tolerance.

Abstract

The aim of this study was to evaluate gene expression in leaf roll tissues of sugarcane plantlets subjected to water restriction under greenhouse controlled conditions using two functional genomics approaches: EST library analysis and differential gene expression by a cDNA macroarray analysis. Sugarcane plantlets of variety SP80-3280 were submitted to water restriction for 17 days and leaf rolls were collected on days 1, 5, 9, 13 and 17 after initiation of the water restriction treatment. Two cDNA libraries were constructed using mRNA isolated from tissues collected at day 9 (LR9 library) and day 17 (LR17 library) and, after sequencing, the generated ESTs were analysed using bioinformatics tools. The results from the EST library analysis showed that transcripts for all the enzymes of the octadecanoid pathway leading to jasmonic acid (JA) biosynthesis were present during both periods, indicating that water-deficit-stress-induced expression of genes was involved in JA production. Transcripts for the antioxidant enzymes catalase, ascorbate peroxidase, polyphenol oxidase and superoxide dismutase were present. A macroarray containing 1202 spotted genes in duplicate were hybridised with cDNAs prepared from mRNA isolated from leaf rolls. An analysis of differentially expressed genes showed that only 147 genes presented differential expression, being induced or repressed. As observed in the cDNA libraries studies, genes coding enzymes of the octadecanoid pathway were induced. Similarly, genes coding antioxidant enzymes (two catalase isoforms, one monohydroascorbate reductase, two ascorbate peroxidase isoforms), indicating the tissue was under oxidative stress.

Introduction

Water deficit is one of the most important environmental stress factors limiting growth and productivity of agronomically important crops (Neill and Burnett, 1999). The changes in metabolism and development induced by stress can frequently be attributed to alterations in the level of gene expression (Taiz and Zeiger, 2004).

A relatively rapid way to obtain information about gene expression is the partial sequencing of cDNAs. Digital analysis of gene expression can be achieved by producing tags, e.g. ESTs, to expressed genes and then inferring transcript abundance from the frequency of these tags (Lee et al., 1995).

The DNA macroarrays enable the identification of activated or deactivated metabolic routes, in addition to the depiction of the hundreds of interactions that occur, at the transcriptional level, in response to several physiological events (Nepomuceno et al., 2001).
Material and methods

Leaf rolls were collected from 48-day-old sugarcane plants (var. SP80-3280) after 9 and 17 days of water restriction. Two leaf roll cDNA libraries, LR3 (9-day water restriction) and LR4 (17-day water restriction), were constructed from mRNA.

Total RNA was isolated using the acidphenol-guanidine-thiocyanate protocol (Chomczynski and Sacchi, 1987). Extraction of mRNA was performed with Oligotex mRNA Mini kit (Qiagen, CA, USA).

Sequencing of cDNA inserts was performed from the 5’ end using the BigDyeTM Terminator Cycle Sequencing v2.0 (PE Biosystems, CA, USA) and the reactions were subjected to automated sequencing in a 3700 DNA Analyser (PE Applied Biosystems).

Macroarray experiments were based on ESTs from the LR9 and LR17 libraries, in which 12 ESTs most highly expressed were arrayed on the membrane together with 34 ESTs classified as no hits and 250 ESTs associated with stress.

The remaining 905 ESTs selected for the array belonged to stress-related metabolic pathways that were identified in the Sugarcane Expressed Sequence Tag (SUCEST) project (Vettore et al., 2003) resulting in a membrane with a total of 1202 ESTs. The membranes were created at Centro Brasileiro de Estocagem de Clones (HTTP://www.bcccenter.fcav.unesp.br).

Results and discussion

A total of 4252 ESTs of good quality (minimum of 140 bases with Phred quality ≥ 20) were obtained for the two libraries under water stress conditions, with 1934 from the LR9 library and 2318 from the LR17 library.

All had the 5’ extremity sequenced and 387 clones also had the 3’ extremity sequenced, with 237 from the LR9 library and 150 from the LR17 library. The mean size of the inserts (ESTs) was 835 bp for the LR9 library and 502 bp for the LR17 library (data not shown).

In the LR9 library, 8 ESTs (0.414%) coding for lypoxygenase (LOX) were observed while, in the LR17 library, 35 ESTs (1.510%) showed significant similarity to this gene. An analysis of the 43 ESTs for LOX present in the LR9 and LR17 libraries showed that they were distributed in 6 clusters (Table 1).

<table>
<thead>
<tr>
<th>Cluster</th>
<th>No. ESTs in the libraries</th>
<th>Results of BLASTX against NCBI (first hit)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LR9</td>
<td>LR17</td>
</tr>
<tr>
<td>JFLR17001D07.g</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>JFLR17011G01.g</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>JFLR9010F11.g</td>
<td>3</td>
<td>17</td>
</tr>
<tr>
<td>JFLR9016D09.g</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>JFLR9042F11.g</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>JFLR9011B01.g</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td>35</td>
</tr>
</tbody>
</table>

Clone analysis revealed the presence of four ESTs for catalase (CAT; three in LR9 and one in LR17), three for ascorbate peroxidase (APX; one in LR9 and two in LR17), five for polyphenol oxidase (PPO; all in LR9) and two for superoxide dismutase (SOD; all in LR17) (Table 2).

To protect cells and subcellular compartments from the harmful effects of ROS, plants synthesise a suite of antioxidant enzymes, among which CAT, SOD, APX and PPO are the most important (Mittler, 2002; Soares and Machado, 2007).
Table 2—ESTs present in the LR9 and LR17 libraries and that codify antioxidant enzymes.

<table>
<thead>
<tr>
<th>Enzyme Cluster</th>
<th>LR9</th>
<th>LR17</th>
<th>Total ESTs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catalase (CAT) JFLR9081A10.g</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Ascorbate peroxidase (APX) JFLR17007F02.g</td>
<td>0</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Polyphenol oxidase (PPO) JFLR9043F11.g</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Superoxide dismutase (SOD) JFLR9075F12.g</td>
<td>3</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>JFLR9084F11.g</td>
<td>2</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>JFLR17025D09.g</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

The data generated by the macroarrays analysis indicated that 147 ESTs exhibited differential expression during the water stress period evaluated. As observed in the cDNA libraries, genes coding enzymes of the octadecanoid pathway were induced. Similarly, genes coding antioxidant enzymes (two catalase isoforms, and two ascorbate peroxidase isoforms) indicated a state of oxidative stress. According to Kumari et al. (2006) the possibility that \( \text{H}_2\text{O}_2 \) oxidative stress produced in response to water deficit, with the direct participation of JA itself, and the stress induced on account of the functioning of the octadecanoid pathway (\( \beta \)-oxidation stage in the peroxisomes/glyoxysomes) can contribute to the activation of genes coding Bowman-Birk (BBI) protease inhibitors.

These two mechanisms could be acting concomitantly during the induction of defensive mechanisms to counter the negative effects of water-deficit stress (Ferro, 2008).

The profiling of the EST clones from the LR9 and LR17 libraries, and the analysis of their expression with macroarrays indicated that the octadecanoid pathway or oxylipin pathway was activated by water stress, appearing more active as the severity of stress increased. During activation of this pathway, JA and \( \text{H}_2\text{O}_2 \) are produced which then lead to induction of antioxidant enzymes, signaling pathway genes and defence gene expression (Figure 1).

![External Stimulus Diagram](image)

Fig. 1—Schematic representation of jasmonic acid (JA) production by the octadecanoid pathway and cellular processes and responses that can be triggered by JA (Ferro, 2008). **AOC**: allene oxide cyclase; **AOS**: allene oxide synthase; **JA**: jasmonic acid; **LOX**: Lipoxygenase; **OPR3**: 12-oxo-PDA reductase (Isoenzyme 3).
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LA GÉNOMIQUE FONCTIONNELLE UTILISER POUR ETUDIER LE STRESS HYDRIQUE CHEZ LA CANNE À SUCRE

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MOTS CLÉS: Stress Hydrique, Expression Différentielle, Réponse au Stress, Tolérance à la Sécheresse.

Résumé

L’OBJECTIF de cette étude consistait à évaluer l’expression génique dans des tissus de feuilles enroulées issues des plantules de canne à sucre sous des conditions contrôlées de serre. Deux approches de génomique fonctionnelle furent utilisées: l’analyse des banques des marqueurs de séquence exprimée (ESTs) et l’expression différentielle de gènes par l’analyse de macroarray d’ADNc. Des plantules de canne à sucre de la variété SP80-3280 furent soumises à une restriction hydrique pendant 17 jours et les feuilles enroulées furent prélevées au bout de 1, 5, 9, 13, et 17 jours après l’initiation du stress hydrique. Deux banques d’ADNc ont été construites en utilisant l’ARNm isolé des tissus prélevés au 9ème (banque LR9) et 17ème jour (banque LR17) et, après le séquençage, les ESTs générés furent analysés en utilisant des outils bioinformatiques. Les résultats des analyses de banques d’EST ont montré que les transcripts pour toutes les enzymes de la voie octadécanoïde de la biosynthèse de l’acide jasmonique étaient présents durant les deux périodes, indiquant que l’expression de gènes induits par un stress hydrique était impliquée dans la production de l’acide jasmonique. Des transcripts pour les enzymes antioxydants suivants: la catalase, l’ascorbate peroxidase, la polyphénol oxidase et la superoxyde dismutase étaient présents. Un microarray contenant 1202 gènes spottés en double ont été hybridés avec les ADNc préparés avec de l’ARNm isolé des feuilles enroulées. Une analyse des gènes exprimés différentiellement a montré que seulement 147 gènes présentaient des expressions différentielles, étant induits ou réprimés. Comme observé dans des études des banques d’ADNc, des gènes codant pour des enzymes de la voie octadécanoïde furent induits. Parallèlement, des gènes codant pour les enzymes antioxydants (deux isoformes de la catalase, une réductase monohydroascorbate, deux isoformes de l’ascorbate peroxydase), furent induits indiquant que le tissu était sous le stress oxydatif.
ENFOQUES EN GENÓMICA FUNCIONAL PARA EL ESTUDIO DEL ESTRÉS HÍDRICO EN LA CAÑA DE AZÚCAR

Por

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PALABRAS CLAVE: Restricción de Agua, Expresión Diferencial, Respuesta al Estrés, Tolerancia a la Sequía.

Resumen

EL OBJETIVO de este estudio fue evaluar la expresión de genes en tejidos foliares de plántulas sometidas a restricción hídrica bajo condiciones controladas en invernadero usando dos enfoques de genómica funcional: el análisis de librerías EST y el análisis de la expresión génica diferencial en una macrocolección de cADN. Las plántulas de caña de azúcar de la variedad SP80-3280 fueron sometidas a restricción hídrica por 17 días y rollos de hojas fueron colectados 1, 5, 9, 13 y 17 días posteriores al tratamiento de restricción hídrica. Las dos librerías de cADN fueron construidas usando mARN aislado de tejidos colectados en los días 9 (librería LR9) y 17 (librería LR17) y, luego de su secuenciación, los ESTs generados fueron analizados usando herramientas de la bioinformática. Los resultados del análisis de la librería de EST mostró que los transcriptos para todos los enzimas de la ruta octadecanoide conducente a la biosíntesis de ácido jasmónico (JA) se encontraban presentes durante ambos períodos, indicando que la expresión génica inducida por el estrés hídrico está involucrada en la producción de JA. Entre los transcriptos presentes se encontraron aquellos para los enzimas antioxidantes de la catalasa, la peroxidasa del ascorbato, la oxidasa polifenólica y la dismutasa superóxido. Una macrocolección conteniendo 1202 genes contados en duplicado fueron sujetos a una hibridación con los cADN preparados a partir de mARN aislados de los rollos de hojas. Un análisis de los genes expresados diferencialmente mostró que sólo 147 genes presentaron expresión diferencial, ya inducida ya reprimida. Tal y como se observó en los estudios de librerías de cADN, se indujeron los genes que codifican para los enzimas de la ruta octadeconoide. De manera similar, se hallaron los genes que codifican a los enzimas antioxidantes (dos isoformas de la catalasa, una reductasa del monohidroascorbato, dos isoformas del peróxido ascorbato), indicando que el tejido estaba bajo estrés oxidativo.
PLANT EXPRESSED CELLULASES FOR THE PRODUCTION OF BIOFUELS

By

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KEYWORDS: Cellulases, Plant Expression, Biofuels, Ethanol, Bagasse.

Abstract

SYNGENTA has pioneered the concept of plant expressed enzymes for biofuel production, and is continuing to develop crops tailored for next generation biofuel production by expressing optimised enzymes in planta for the conversion of cellulose to fermentable sugars. Agricultural waste streams such as corn stover, corn cobs and sugarcane bagasse are attractive potential feed stocks for advanced second generation biofuels due to their comparatively low cost, abundance and availability. A sugarcane mill processing 7 million t/y will generate close to 2 million t/y of wet bagasse. Given that about one quarter of this material is cellulose, then more than 12 000 t/y of enzymes are needed at current enzyme loadings to convert the cellulose to fermentable sugar. Producing this much enzyme by microbial fermentation requires twelve 100 000 L/d fermentors operating at 100 g enzyme/L ferment for a year. In an alternative approach, Syngenta has demonstrated the production of several classes of cellulases in maize and shown that they are nearly as active as their microbially produced counterparts. Furthermore, maize- expressed cellulases were tested on pre-treated sugarcane bagasse. To make sugarcane production and delivery of cellulases a reality, Syngenta recently formed the Syngenta Center for Sugar cane Biofuel Development (SCSBD) in collaboration with the Queensland University of Technology, Brisbane, Australia to develop efficient sugarcane transformation technologies. By providing technologies like these, Syngenta is helping to make second generation biofuels economically viable, while reducing agricultural waste and increasing the value realised from a hectare of land.

Introduction

Many governments have passed legislation promoting biofuel production. For example, the European Union has specified that 5.75% of its overall transport fuel should come from renewable sources by 2010, and that this level should rise to 10% by 2020, while the United States passed the Energy Independence and Security Act (EISA) in December of 2007 that sets a target of 136 billion L of ethanol by 2025 with 80 billion L coming primarily from cellulosic ethanol.

Initiatives like these, along with Brazil’s ethanol mandate have driven fuel ethanol production from 30 billion L in 2000 to over 65 billion L in 2008 (Renewable fuels association, 2009; Berg, 2001). With steep projected growth in the bioethanol markets, Syngenta has pioneered the concept of plant-expressed enzymes to make converting plant materials to fermentable sugars more efficient and cost effective.

Advanced traits are needed for ‘second generation’ biofuels. Cellulosic ethanol (ethanol from cellulose) is viewed as truly ‘renewable’ but is currently expensive due to high capital and
enzyme costs. One analysis of industry data showed that enzymes cost $0.59/L cellulosic ethanol (Bon and Ferrara, 2007). Even with a selling price of $1.00/L ethanol, this cost is too high for successful commercialisation. By comparison, enzyme costs for the corn dry-grind process were about forty times cheaper, estimated at $0.014/L ethanol (Galbe et al., 2007).

The main reason for the higher cost is that more enzyme (25 kg/t) is required to convert cellulose to ethanol than is required for starch to ethanol processes (1.9 kg/t) (Somerville, 2007; McAloon et al., 2000). Reducing the cost of the enzyme is critical to making this a practical technology. Syngenta estimates that the enzyme cost can be reduced to under $0.02/L ethanol by producing the enzymes in planta.

In this scenario, the main cost component would be separation of the enzymes from the biomass if an enzyme unfriendly process (e.g. acid/steam hydrolysis) is used, though other process models might include ammonia-fibre-explosion (AFEX), or an enzymatic pre-treatment process.

Efficient conversion of cellulose to fermentable sugars typically requires four fungal enzymes: two cellobiohydrolases (CBHI and CBHII), endoglucanase (EG), and beta-glucosidase. Here we report on the expression of the cellobiohydrolase enzymes in Zea mays.

Results

Gene cassettes were made to target accumulation of CBHI or CBHIII to the cytoplasm, endoplasmic reticulum (ER), or apoplast and transformed into maize. Studies evaluated subcellular targeting in both seed, and vegetative tissues.

Figure 1 shows the results for individual T1 transformants expressing CBHI in seed. Subcellular targeting of CBHI was found to affect both the numbers of transformants showing activity and the level of activity seen. Targeting the protein to the ER produced more plants with high activity levels than did cytoplasmic, or apoplastic targeting.

![Fig. 1—Relative activity levels of Trichoderma reesei CBHI from transgenic maize seed. Expression was sub-cellularly targeted to cytoplasm, apoplast or ER. Each bar represents relative activity from a single transgenic event. Relative activity (arbitrary units) was determined by extracting protein from 25 ground T1 maize seed and measuring activity of 1 mg of total soluble protein (TSP) on p-nitrophenyl-β-D-lactopyranoside, a chromogenic soluble substrate. Fungal controls were made by dosing 200 mg ground wild type flour with 0, 181, or 362 g/g of purified Trichoderma reesei CBH I protein purchased from Megazyme (Megazyme, International, Ireland) prior to protein extraction.]
Mature maize leaves were collected from two high activity T2 events and the protein levels were determined. Results shown in Figure 2 indicate that 7%–10% of total soluble protein (TSP) in the T2 generation was CBHI.

![Figure 2](image)

**Fig. 2**—Estimated fraction of TSP that was CBHI (Syngenta proprietary) in T2 maize leaves. Two events are shown: orange bars are for event A and blue bars are for event B. The first two bars for each event are T2 siblings from the same T1 parent, while the second two bars are T2 siblings from a different T1 parent for the same event. Both events were ER targeted and vegetatively expressed CBHI. Activity of 1 mg of TSP on 4-methylumbelliferyl-β-D-lactoside was measured and the percentage of active CBHI was calculated by dividing the rate of the reaction by the specific activity of the same microbially expressed protein to give the amount of active CBHI. This was divided by the total amount of TSP and expressed as a percent. Error bars represent standard deviations of extraction replicates n = 4 (one biological sample).

To ensure that the plant-made enzymes are as effective as their microbial counterparts, the plant-produced enzymes were tested in head to head reactions in enzyme cocktails on pre-treated sugarcane bagasse.

For CBHI, enzyme cocktails were prepared containing EG, CBHII and either a plant produced or microbially produced version of CBHI loaded on an equal mg protein basis and then used to digest pre-treated sugarcane bagasse (acid/steam pre-treatment process). The results shown in Figure 3 indicate that, in a cocktail, the purified plant produced CBHI performed as well as the purified microbial protein.

For CBHI, the test was repeated with the plant produced version of the protein loaded on an equal activity basis on a soluble, fluorescent substrate 4-methylumbelliferyl-β-D-lactoside (MUL) with similar results. Similar tests were done for CBHII with CBHII loaded on an equal activity on phosphoric acid swollen cellulose (PASC); however, CBHI was left out of the cocktail so that the difference between the plant and microbial versions of CBHII could be more clearly seen.

Based on the PASC results, plant produced CBHII was loaded at 90% that of purified microbial CBHII (on a mass basis) due to its higher specific activity on PASC.

The results in Figure 4 indicate that the plant produced CBHII had 64%–77% the activity of the microbial version on pre-treated cane bagasse at this loading.
Fig. 3—Performance of a purified, seed expressed, ER targeted *Trichoderma reesei* CBHI on acid/steam pre-treated sugarcane bagasse. Results are expressed as a percentage of the performance of a purified, microbially produced CBHI (Syngenta proprietary). All reactions contained CBHII and an EG. Samples of the reactions were taken after incubating at 40°C with agitation at 300 rpm for zero h, 16 h and 72 h and the percent hydrolysis was determined. Enzyme loadings were 12 mg of each enzyme per gram cellulose except for the negative control where CBHI was omitted. All reactions were done in triplicate. Error bars are standard error (n = 3).

Fig. 4—Performance of purified, vegetatively expressed, ER targeted, CBHII on acid/steam pre-treated sugarcane bagasse. Results are expressed as a percentage of the performance of a purified, microbially produced version of the same enzyme. EG and the microbially produced CBHII were used at 7 mg/g cellulose, while the purified plant CBHII loadings were matched based on activity on PASC. Plant produced CBHII was used at 6.4 mg/g cellulose based on its higher PASC (specific) activity. Samples of the reactions were taken after incubating at 40°C with agitation at 300 rpm for zero h, 15 h, 25 h, 48 h and 72 h and the percent hydrolysis was determined. All reactions were done in triplicate. Error bars are standard error (n = 3).
Discussion and conclusions

The work presented here shows that it is possible to produce cellubiohydrolases at high levels (7–10% of TSP) in plants, and that these CBH enzymes have good activity against pre-treated sugarcane bagasse. If the expression levels obtained in maize can be achieved in sugarcane, it will be possible to use cane itself to produce enough enzyme for converting the cellulose in bagasse to ethanol.

A cane mill processing 7 million t/y of cane produces about 980 000 t/y of dry bagasse. Since only about half of dry bagasse is cellulose, the current enzyme requirements are close to 12 000 t/y of enzyme.

Preliminary data from maize suggests that we can meet this requirement and produce enough extra enzyme to account for the small performance differences seen in the plant produced enzyme. This is important information for a process model because these plant produced CBH enzymes were tested on pre-treated cane bagasse that is believed to be an important target for the cellulosic ethanol industry.

While the enzymes used in this study were produced in maize, the Syngenta Center for Sugarcane Biofuel Development at Queensland University of Technology, Brisbane, Australia, is developing efficient cane transformation technologies focusing on cane produced cellulases (Sainz and Dale, 2009).

By showing that these enzymes can be produced at relevant levels and are active on important substrates, Syngenta is contributing to making this new technology a reality which might lead to the creation of new products for the SC industry.

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LA PRODUCTION DES BIOCARBURANTS DANS LES PLANTES QUI EXPRIMENT LA CELLULASE

Par

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MOTS CLÉS: Cellulases, Expression dans la Plante,
Biocarburants, Éthanol, Bagasse.

Résumé
SYNGENTA a été le pionnier dans la conception de la production des biocarburants dans les plantes qui expriment des enzymes. Elle continue à développer de nouvelles générations de plantes pour la production des biocarburants en exprimant des enzymes in planta pour la transformation de la cellulose en sucres fermentescibles. Les déchets agricoles, composés de tiges et d’épis de maïs ainsi que la bagasse de la canne à sucre, sont considérés comme d’éventuelles sources attrayantes pour la production des biocarburants de deuxième génération en raison de leur coût relativement faible, leur abondance et leur disponibilité. Une usine qui peut transformer 7 millions tonnes de canne par an peut générer près de 2 millions tonnes de bagasse fraîche. Etant donné que près d'un quart de cette matière est composée de la cellulose, plus de 12 000 tonnes d'enzymes par an sont nécessaires pour transformer la cellulose en sucres fermentescibles. La production de cette quantité d’enzyme par la fermentation microbienne nécessite douze fermenteurs avec une capacité de 100 000 L par jour et fonctionnant à 100 g d’enzyme/L de ferment durant toute l’année. Syngenta a démontré la possibilité de produire différents types de cellulases dans le maïs et elles sont aussi actives que leurs homologues microbiennes. De plus, les cellulases exprimées chez le maïs ont été testées sur de la bagasse pré-traitée de la canne à sucre. Dans le but de développer des technologies efficaces pour la production et la transformation de la canne à sucre et de rendre possible la production de la cellulase, Syngenta a récemment créé le ‘Syngenta Center for Sugarcane Biofuel Development’ (SCSBD), en partenariat avec l’Université de Technologie de Queensland, en Brisbane, Australie. Avec de telles technologies, Syngenta contribue à faire de la deuxième génération de biocarburants une opération économiquement viable, tout en réduisant les déchets agricoles et en augmentant les bénéfices obtenus à partir d'un hectare de terre.
EXPRESIÓN DE CELULASES EN PLANTAS PARA LA PRODUCCIÓN DE BIOCOMBUSTIBLES

Por

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PALABRAS CLAVE: Celulasas, Expresión en Plantas, Biocombustibles, Etanol, Bagazo.

Resumen

SYNGENTA ha sido pionera en el concepto de la expresión de enzimas en plantas para producir biocombustibles, y continúa el desarrollo de cultivos diseñados para la siguiente generación de biocombustibles al expresar enzimas optimizadas in planta para la conversión de celulosa en azúcares fermentables. Los flujos de residuos agrícolas como el rastrojo de maíz, las mazorcas de maíz y el bagazo de la caña de azúcar son atractivas materias primas con potencial en la segunda generación avanzada de biocombustibles debido a su costo comparativamente bajo, abundancia y disponibilidad. Un molino de caña de azúcar procesando 7 millones t/a generará cerca de 2 millones t/a de bagazo húmedo. Dado que cerca de un cuarto del material es celulosa, entonces más de 12 000 t/a de enzimos serían necesarios, a niveles actuales de producción, para convertir celulosa en azúcar fermentable. La producción de tanto enzimo por fermentación microbiológica requeriría 100 000 L/d de fermentadores operando a una capacidad de 100 g de enzimo/L de fermento durante un año. En un enfoque alternativo, Syngenta ha demostrado la producción de diversas clases de celulasas en el maíz y mostró que son casi tan activas como sus contrapartes producidas de manera microbiana. Además, las celulasas expresadas en maíz fueron evaluadas en bagazo de caña de azúcar tratadas previamente. Para hacer realidad la producción de caña de azúcar y la entrega de enzimos, Syngenta recientemente formó el Centro Syngenta para el Desarrollo de Biocombustibles de la Caña de Azúcar (SCSBD, por sus siglas en Inglés), en colaboración con la Universidad de Tecnología de Queensland, Brisbane, Australia, a fin de desarrollar tecnologías eficientes de transformación de caña de azúcar. Al proveer de tales tecnologías, Syngenta está ayudando a hacer económicamente viables los biocombustibles de segunda generación, mientras reduce el desecho agrícola e incrementa el valor derivado de un hectárea de tierra.
ISOLATION AND CHARACTERISATION OF A GENE ENCODING THE \( \Delta^1 \)-PYRROLINE-5-CARBOXYLATE SYNTHETASE IN SUGARCANE (\textit{Saccharum} spp HYBRID VAR. ROC22)

By

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KEYWORDS: Sugarcane, \( \Delta^1 \)-Pyroline-5-Carboxylate Synthetase (P5CS) Gene, Proline, Water Stress.

Abstract

SUGARCANE variety ROC22 was used as the experimental material. Water stress treatment was performed on 4 to 5-leaf stage plants with a 25% polyethylene glycol (PEG) 6000 solution. A cDNA sequence for the ScP5CS sugarcane gene was isolated by homologous cloning. The sequence contained 2151 bp and an open reading frame of 716 amino acids (GenBank accession number EU005373). Comparing the sequence of ScP5CS with that of sugarcane P5CS reported in GenBank, the nucleotide sequence (EF155655) showed high identity (98%), but the deduced amino acid was only 92% identical. The deduced protein contained a putative ATP-binding site, putative leucine domains, a Glu-5-kinase domain, a putative NADPH-binding domain, a conserved GSA-DH domain and a feedback inhibition site. Besides, there were differences in the Glu-5-kinase domain from the reported deduced amino acid sequence of P5CS (ABM30223), but less for the P5CSs from rice (\textit{Oryza sativa}) and wheat (\textit{Triticum aestivum}). So we believe this gene to be a new gene of sugarcane P5CS.

Introduction

Proline is accumulated under drought and salinity stress in a number of plant species and it is thought to play an important role in plant cells for adaptation to water stress. Proline is synthesised via two routes from either glutamate (Glu) or ornithine (Orn) in eukaryotes, specifically in higher plants and its accumulation is mainly from Glu (Delauney and Verma, 1993).

High-level expression of \( \Delta^1 \)-pyrroline-5-carboxylate synthetase (P5CS), a bifunctional enzyme that catalyses the first and second reactions of proline biosynthesis, which exhibit both \( \gamma \)-GK and GSA dehydrogenase activities, has been reported to increase salinity stress tolerance in transgenic tobacco plants (Kishor \textit{et al}., 1995).

In \textit{Vigna aconitifolia} and \textit{Arabidopsis}, the first two steps of proline biosynthesis from Glu are catalysed by P5CS (Hu \textit{et al}., 1992; Savouré \textit{et al}., 1995; Yoshiha \textit{et al}., 1995).

Several genes encoding the enzymes in the route of proline biosynthesis have been identified in a number of plant species, namely \textit{Arabidopsis thaliana}, petunias, \textit{Triticum aestivum} L. and \textit{Oryza sativa} L. Functional analysis showed that all have been reported to be up regulated in response to water deprivation and/or salinity (Hare and Cress, 1997; Hare \textit{et al}., 1998; Yamada \textit{et al}., 2005; Ma, 2005; Igarashi \textit{et al}., 1997). The genes encoding P5CS have been cloned from
Arabidopsis thaliana, rice (Oryza sativa), wheat (Triticum aestivum), alfalfa (Medicago sativa), tomato (Lycopersicon esculentum), lettuce (Lactuca sativa), soybean (Glycine max.), radish (Raphanus sativus), grape (Vitis vinifera), and moth bean (Vigna aconitifolia).

In this paper, we report on the isolation and structure of the ScP5CS gene in sugarcane as well as the features of the encoded polypeptide.

Materials and methods

Plant growth and salt-stress treatment

Seed cane of sugarcane variety ROC22 was germinated and grown in the laboratory. Water stress treatment was performed when the plants had developed 4–5 leaves. The plants were treated with a 25% polyethylene glycol (PEG) 6000 solution. Control plants were treated with deionised water. Leaf samples were taken for RNA extraction 18–24 h after treatment.

Cloning and sequencing of P5CS cDNA from sugarcane leaves

Total RNA was extracted from young leaves from both treated and control plants. PCR amplification was conducted using the procedures described by Wang and Fang (2002). The P5CS cDNA fragment was amplified from the total pool of cDNA, using gene specific primers designed with reference to the known P5CS gene sequences (GenBank accession number: EF155655, AY574031, D49714, AY888045, DQ864376).

The cDNA for PCR was synthesised in a standard first strand reaction using 0.5–5 µg of total RNA from leaves with 20 units of avian myeloblastosis virus reverse (AMV) transcriptase (Takara). The cDNA was subjected to 35 cycles of amplification in a 25 µL reaction mixture containing 0.4 µM of each primer, 0.2 mM each of dATP, dTTP, dGTP, and dCTP, 10×PCR Buffer (MgCl₂ plus) and 1.25 units of Taq DNA polymerase.

Each amplification cycle consisted of 3 min at 94°C, then 1 min of denaturation at 94°C, 40 s of annealing at 53°C, and 90 s of extension at 72°C, with a final extension for 10 min at 72°C. The PCR products (10 µL) were size fractionated by electrophoresis through 1% agarose gels and extracted from the gels. The amplified cDNA was cloned and sequenced, and named ScP5CS.

Sequence analysis

The analyses of DNA and protein sequences were performed using DNAMAN Software package and BLAST program of the NCBI. Homology alignment was performed using the Clustalx 1.83 and ClustalW program.

Results

Isolation, sequencing, and characterisation of sugarcane ScP5CS cDNA

The complete nucleotide sequence of a P5CS cDNA clone, ScP5CS, was cloned. The sequence of 2151 bp contained a single major open reading frame encoding a polypeptide of 77762.0 Da for a putative protein of 716 amino acids with a calculated isoelectric point of 6.29 (GenBank accession number EU005373).

Translation would be initiated from the first ATG codon, at the 5’ end of the coding strand. Comparing the sequence of ScP5CS with that of sugarcane P5CS reported in GenBank revealed sequence similarity of 98%, although the deduced amino acid was only 92% similar. However, the isolated cDNA showed 85% and 84% overall sequence similarity to those of rice (Oryza sativa) and wheat (Triticum aestivum) respectively.

Interestingly, the putative ATP-binding site, putative leucine domains, Glu-5-kinase domain, putative NADPH-binding domain, conserved GSA-DH domain and feedback inhibition site were present in each of the enzymatic domains of sugarcane ScP5CS (Chiang et al., 1995; Ma, 2005; Hu et al., 1999). There were more differences in Glu-5-kinase domain from the deduced amino acid of the reported sugarcane P5CS (ABM30223), but less for the P5CSs from rice (Oryza sativa) and wheat (Triticum aestivum) (Figure 1).
Fig. 1—Sequence alignment of the predicted ScP5CS amino acid sequence of sugarcane with the P5CS protein sequences of graminaceous plants, AAS89034, BAA19916 (Oryza sativa); AAX35536, BAD97364
Sugarcane ScP5CS contains domains homologous to *E. coli* proA and proBA proteins

The ScP5CS clones efficiently complemented *E. coli* proA and proBA, but not proC, the predicted two domains showed high homology to the *E. coli* proBA and proA proteins, and the recombinant ScP5CS protein showed GSA-dependent γ-GK enzyme activity. High homology was also observed to the bacterial and yeast γ-glutamyl kinase at the N-terminus and to the bacterial γ-glutamyl phosphate reductase at the C-terminus of the ScP5CS protein. Searching in GenBank resulted in the conserved domain of the deduced amino acid sequences of sugarcane ScP5CS, which is shown in Figure 2.

**Discussion**

In this study, the cDNA and corresponding gene of ScP5CS encoding the Δ¹-pyrroline-5-carboxylate synthetase from sugarcane variety ROC 22 was successfully isolated and the features of the encoded polypeptide characterised. Comparing the sequence of ScP5CS with that of sugarcane P5CS reported in GenBank, the nucleotide acid sequences showed high identity (98%), but the deduced amino acid homology was only 92%. The alignment of ScP5CS with all the presently available similar proteins in GenBank revealed two enzymatic domains corresponding to bacterial and yeast γ-glutamyl kinase and to bacterial γ-glutamyl phosphate reductase. The two residues in the positions 125 and 128, which were aspartate (Asp, D) and phenylalanine (Phe, F) respectively, were conserved in sugarcane ScP5CS and other plants. Site-directed mutagenesis could indicate whether they are implicated in the feedback inhibition by proline.

Amino acid sequence analysis revealed the identical sequences between the ScP5CS and graminaceous plants. There were more differences in Glu-5-kinase domain from the deduced amino acid of the reported sugarcane P5CS (ABM30223), but less for the P5CSs from rice (*Oryza sativa*) and wheat (*Triticum aestivum*). Different molecular structures would lead to different functions for the ScP5CSs. Presently, further functional analysis of this gene is being studied. Characterisation of events underlying P5CS gene expression is currently under investigation, which could provide insights into the role of proline and stress-related changes in gene expression in abiotic stress tolerance of sugarcane.

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ISOLEMENT ET CARACTÉRISATION D’UN GÈNE CODANT POUR LA $\Delta^1$ PYRROLINE 5 CARBOXYLATE SYNTHÉTASE CHEZ LA CANNE À SUCRE (SACCHARUM SPP. HYBRIDE VAR. ROC22)

Par

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*Mots Clés: Canne à Sucre, $\Delta^1$ Gène Pyrroline 5 Carboxylate Synthétase (P5CS), Proline, Stress Hydrique.

Résumé

Cet article décrit l’isolement et la caractérisation d’un gène codant pour la $\Delta^1$ pyrroline 5 carboxylate synthétase chez la canne à sucre (Saccharum spp. var. hybride ROC22). Des plantules au stade de quatre à cinq feuilles sont soumises à un stress hydrique via l’application d’une solution de 25% polyéthylène glycol (PEG). La séquence ADNc correspondant au gène ScP5CS de la canne à sucre a été isolée par clonage homologue. Cette séquence de 2151 pb, qui contient un ORF (Open Reading Frame) codant 716 acides aminés (numéro d’accession Genbank: EU005373), partage un fort pourcentage d’identité (98%) avec les séquences du gène P5CS (EF155655) chez la canne à sucre. Cependant, le pourcentage d’identité en acides aminés n’est que de 92%. La protéine déduite possède un site putatif de fixation au NADPH, des domaines leucine conservés, un domaine Glu5-kinase, un domaine GSA-DH ainsi qu’un site de rétro-inhibition. Des différences ont été observées au niveau du domaine Glu-5 kinase de ScP5CS avec les séquences en acides aminés de P5CS (ABM30223). Cependant ces différences sont moins importantes qu’avec les séquences du riz (Oryza sativa) et du blé (Triticum aestivum). Le gène isolé correspondrait donc à un nouveau gène P5CS chez la canne à sucre.
AISLAMIENTO Y CARACTERIZACIÓN DE UN GEN QUE CODIFICA LA \(\Delta^1\)-PIRROLINA-5-CARBOXILATO SINTETASA EN CAÑA DE AZÚCAR (HÍBRIDO DE SACCARUM SPP VAR. ROC22)

Por

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PALABRAS CLAVES: Caña de Azúcar, Gene \(\Delta^1\)-Pirrolina-5-Carboxilato Sintetasa (P5CS), Prolina, Estrés Hídrico.

Resumen

La variedad de caña ROC22 fue utilizada como el material experimental en el presente estudio. Plantas de dicha variedad que tenían de 4 y 5 hojas fueron sometidas a estrés hídrico aplicándoles una solución de Polietilenglicol (PEG) 6000 al 25%. La secuencia de cADN que codifica para el gen de caña ScP5CS fue aislada por clonación homologa. La secuencia del gen estaba compuesta de 2151 pb con un marco de lectura abierto de 716 aminoácidos. (Acceso en GenBank número EU005373). Al comparar la secuencia de ScP5CS con la secuencia del gen de caña de azúcar P5CS registrado en GenBank, mostró que la secuencia nucleotídica (EF155655) tenía una identidad del 98%, pero la secuencia a nivel de aminoácido fue solo idéntica en un 92%. La proteína contiene un sitio de unión a ATP, un dominio de leucina, un dominio para Glu-5-quinasa, un dominio de unión NADPH, un dominio conservado de GSA-DH y un sitio de reacción inhibición. Adicionalmente, se encontraron diferencias a nivel de la secuencia para el dominio Glu-5-quinasa comparadas con las registradas para la secuencia de aminoácidos de P5CS (ABM30223), y menos diferencias al compararlas con la secuencia del gen P5CSs de arroz (Oryza sativa) y trigo (Triticum aestivum). Por lo tanto creemos que este gen es un nuevo gen de P5CS en caña de azúcar.
AN IN VITRO INDUCED MUTAGENESIS PROTOCOL FOR THE PRODUCTION OF SUGARCANE TOLERANT TO IMIDAZOLINONE HERBICIDES

By

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KEYWORDS: Ethyl Methanesulfonate, Imazapyr, Somatic Embryogenesis.

Abstract

THE MAIN objective of this study was to establish a protocol for the production of imidazolinone-tolerant sugarcane genotypes through in vitro induced mutagenesis. The approach involved using the chemical mutagen ethyl methanesulfonate (EMS) to induce a single target-site mutation in the acetolactate synthase gene, and testing the tolerance of regenerated plants with the herbicide Arsenal (250 g/L imazapyr). The initial work determined the mutagenic (8 mM and 16 mM EMS for 4h) and in vitro screening conditions (LD$_{50}$ = 0.042 µM, LD$_{90}$ = 0.08 µM imazapyr in the medium) for 6–10 week-old somatic embryogenic calli of the N12 sugarcane cultivar, and the screening treatment for ex-vitro control plants (spraying with Arsenal in the greenhouse). As the culture conditions (which included 2,4-D) alone did not cause a significant production of somaclones, the mutagenic agent was essential to increase the chance of producing herbicide tolerant plantlets. The EMS and imazapyr treatments were then applied in combination and the calli were exposed to increasing levels (0.042–0.16 µM) of herbicide. Putative tolerant plants have been obtained but their regeneration was slower than the control; after acclimatisation they will be sprayed with Arsenal (102 g a.i./ha; 0.39 M). For all treatments, callus mass, number of green, albino and abnormal plantlets, and biomass of acclimatised plants were recorded, and amplified fragment length polymorphism analyses were performed on the regenerated plants.

Introduction

Imidazolinone herbicides (e.g imazapyr) control weeds by inhibiting acetolactate synthase (ALS), which is involved in the biosynthesis of essential branched-chain amino acids. Any of several single target-site (dominant) mutations (Tan et al., 2005), in five conserved regions on the enzyme (Webster and Masson, 2001), reduce target site sensitivity (Yu et al., 2003), thereby conferring resistance to the herbicide. Such mutations occur during in vitro morphogenesis caused by culture conditions (e.g. auxins) resulting in somaclonal variant cells, which can then be regenerated into variant plants.

An example in sugarcane is the generation of cell lines, which yielded plants with a five-fold tolerance to glyphosate (Zambrano et al., 2003). This approach can be further enhanced by mutagenic agents (e.g. EMS) (Van Harten, 1998). To-date, efforts in the production of herbicide tolerant sugarcane genotypes have focused on genetic engineering but in vitro mutagenesis may offer a potential alternative to recombinant DNA technologies. This study aimed at assessing such an option.
Materials and methods

The somatic embryogenesis protocol of Snyman (2004) was followed using immature leaf rolls of *Saccharum* spp. hybrid var. N12: 1) calli were induced on MS, 20 g sucrose, 8 g agar and 3 mg 2,4-D per L (6–10 weeks); 2) embryo germination was on the same medium devoid of 2,4-D (6–8 weeks); 3) plantlets were established on ½ MS, 5 g sucrose and 8 g agar per L (4 weeks); and 4) plants were acclimatised in a misting chamber (1 min every 6 h) for 3 days, before transfer to a polytunnel. All cultures were subcultured onto fresh media fortnightly.

Calli (0.2 g) were exposed to 10 mL of ethyl methanesulfonate (EMS) (0–96.6 mM) for 4 h, rinsed and placed on callus medium. Imazapyr (Sigma-Aldrich; Pestanal®) was prepared as 5 M in 10 mM potassium phosphate (pH 7.5), and required aliquots were added to the media. Imazapyr concentrations in the media were 0–0.1 µM for callus and 0–20 µM for established plantlets.

Various mutagen and herbicide concentrations were tested in combination, and with step-wise increases of imazapyr. *Ex-vitro* plants were sprayed with 9.25–262.5 g a.i./ha; 0.036–1 M) Arsenal (BASF; 250 g/L imazapyr) after acclimatisation. Measurements included callus and plantlet biomass, % plant regeneration and survival, and Amplified Fragment Length Polymorphism (AFLP) analyses.

Results and discussion

The strategy employed in this study was to induce somaclonal variation in embryogenic callus cells (with and without mutagen exposure), followed by *in vitro* selection of imazapyr tolerant cells and then further screening of the putative tolerant plants regenerated from them.

The indirect somatic embryogenesis protocol used here resulted in a relatively low frequency of somaclonal variants, as previously reported for a direct method (Watt *et al*., 2009).

The results (including AFLPs) obtained from the control (0 EMS, 0 imazapyr) (±7% abnormal plants) and herbicide-only selection indicated that 2,4-D did not induce much somaclonal variation. This confirmed the premise that a mutagen was essential to increase the frequency of new cell lines in culture. The chemical mutagen EMS was therefore employed as it causes high frequency of gene mutations and low frequency of chromosomal aberrations (Van Harten, 1998).

Each step of the protocol was first established, with conclusions based on biomass, plantlet regeneration and AFLP analyses. From the EMS-only treatment (i.e. no imazapyr in the medium), 8 mM and 16 mM EMS were selected for further studies.

The LD$_{50}$ and LD$_{90}$ for % plantlet inhibition by imazapyr were 0.042 µM and 0.08 µM, respectively. The spraying treatment deemed suitable for screening *ex-vitro* plants in the greenhouse was 102 g a.i./ha (0.39 M) Arsenal.

Table 1 shows an example of the results obtained for some of the tested combinations of the mutagenic (16 mM EMS) and *in vitro* selection treatments. The indirect somatic embryogenesis protocol (control) routinely yields approximately 400–500 plantlets/g fresh mass; predictably, plantlet yield decreased and regeneration time increased with increasing stringency of EMS and imazapyr regimes.

All of the potentially imazapyr-tolerant subclones, including those treated with 8 mM EMS (results not shown) are being further screened and assessed. The tolerant genotypes will also to be evaluated in the field to determine phenotypic effects and the level of whole plant tolerance to the herbicide.

In sugarcane, glyphosate- (Zambrano *et al*., 2003) and red rot- tolerant plants (Singh *et al*., 2008) have been obtained by selection of mutant lines, which arose randomly in response to culture media pressure.
Table 1—Plantlet regeneration after mutagenic treatment with 16 mM EMS and selection on various imazapyr regimes. The standard protocol (no EMS, no imazapyr) yielded 488±99.3 and 35±9.4 plants/g callus fresh mass normal and abnormal (albino and visually chimaeric) plants, respectively. n = 5, mean ± SE.

<table>
<thead>
<tr>
<th>Culture stage weeks in culture</th>
<th>Callus induction (µM)</th>
<th>Embryo germination and plantlet establishment (µM)</th>
<th>Normal plants</th>
<th>Abnormal plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0</td>
<td>0.042</td>
<td>201±67.3</td>
<td>33±13.9</td>
</tr>
<tr>
<td></td>
<td>0.063</td>
<td>204±15.4</td>
<td>14±14.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.08</td>
<td>26±21.9</td>
<td>4±3.6</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.042</td>
<td>0.08</td>
<td>161±32.7</td>
<td>89±78.6</td>
</tr>
<tr>
<td></td>
<td>0.12</td>
<td>2±2.2</td>
<td>5±4.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.16</td>
<td>2±1.6</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.08</td>
<td>0.08</td>
<td>19±2.4</td>
<td>40±30.3</td>
</tr>
<tr>
<td></td>
<td>0.12</td>
<td>3±1.7</td>
<td>2±1.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.16</td>
<td>9±12.9</td>
<td>17±12.9</td>
<td></td>
</tr>
</tbody>
</table>

By increasing the mutation frequency, the protocol reported here has the potential to be more efficient in generating and selecting variability for these and other important traits.

REFERENCES


UN PROTOCOLE POUR LA MUTAGÉNÈSE INDUITE \textit{IN VITRO}
POUR LA PRODUCTION DE CANNE À SUCRE TOLÉRANTE
AUX HERBICIDES IMIDAZOLINONE

Par

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MOTS CLÉS: Éthylméthane Sulfonate, Imazapyr,
Embryogénèse Somatique

Résumé

L’OBJECTIF principal de cette étude était d’établir un protocole pour la production de génotypes de canne à sucre tolérants à l’imidazolinone à travers la mutagénèse induite \textit{in vitro}. L’approche consistait en une utilisation d’un mutagène chimique, l’éthylméthane sulfonate (EMS), pour induire une mutagénèse dirigée dans le gène acétolactate synthase, suivi d’une évaluation de la tolérance des plantes régénérées à l’herbicide Arsenal (250 g/L imazapyr). Une étude initiale a établi la concentration du mutagène (8 mM et 14 mM EMS pendant 4 h), les conditions de sélection \textit{in vitro} (LD50 = 0.042 µM, LD90 = 0.08 µM imazapyr dans le milieu) pour le développement des cals embryogènes somatiques âgés de 6 à 10 semaines de la variété N12 et pour une évaluation des plantes témoins en serre (avec un traitement à l’herbicide Arsenal). Comme les conditions de culture (qui incluaient le 2,4-D) à elles seules n’ont pas produit un nombre significatif de somaclones, l’agent mutagène était essentiel pour augmenter la chance d’obtenir des plantules tolérantes à l’herbicide. Les traitements EMS et imazapyr ont ensuite été appliqués simultanément et les cals exposés à des taux croissants (0.042 – 0.16 µM) d’herbicide. Des plantes tolérantes putatives ont été obtenues mais leur régénération était plus lente que celle du témoin. Après une acclimatation, les plantes seront pulvérisées avec de l’Arsenal (102 g a.i/ha ; 0.39 M). Pour chaque traitement, le poids du cal, le nombre de plantules vertes, albinos et anormales ainsi que la biomasse des plantes acclimatées ont été notés. Des analyses de polymorphisme de longueur des fragments amplifiés (A
PROTOCOLO DE LA INDUCCIÓN IN VITRO DE UNA MUTAGÉNESIS
PARA LA PRODUCCIÓN DE CAÑA DE AZÚCAR TOLERANTE
A LOS HERBICIDAS CON BASE EN IMIDAZOLÍNONA

Por

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PALABRAS CLAVE: Etil Metanosulfonato, Imazapyr,
Embriogénesis Somática.

Resumen
EL OBJETIVO principal de este estudio fue establecer un protocolo para la producción de genotipos de caña de azúcar tolerantes a la imidazolínona mediante la inducción in vitro de una mutagénesis. El enfoque involucró el uso del mutágeno químico denominado etil metanosulfonato (EMS), el cual induce una mutación en un sitio específico del gen sintasa de acetolactato, y en la evaluación de plantas regeneradas tolerantes al herbicida Arsenal (250 g/L de imazapyr). El trabajo inicial permitió definir las condiciones mutagénicas (8 mM y 16 mM EMS por 4h) de criba in vitro (LD₅₀ = 0.042 µM, LD₉₀ = 0.08 µM de imazapyr en el medio de cultivo) para callos embriogénicos (de alrededor de 6 a 10 semanas) del cultivar de caña de azúcar N12, y de una metodología de criba ex vitro para las plantas control (con aspersión del herbicida Arsenal en el invernadero). Debido a que las condiciones de cultivo (incluyendo el 2,4-D) no ocasionaron por sí mismas una producción significativa de somaclonas, se consideró al agente mutagénico como crucial en el incremento de la producción de plántulas tolerantes al herbicida. Posteriormente, los tratamientos de EMS e imazapyr fueron aplicados en conjunto, sometiendo a los callos a diferentes niveles de herbicida (0.042 – 0.16 µM). Si bien se obtuvieron supuestas plantas tolerantes, su regeneración fue más lenta que el control; luego de una aclimatación se les roció con Arsenal (102 g a.i./ha; 0.39 M). En todos los tratamientos, se registraron masas de callo, número de plántulas normales, anormales y albinas, y la biomasa de plantas aclimatizadas. Asimismo, se condujeron análisis del polimorfismo en fragmento amplificado (AFLP, por sus siglas en Inglés) en aquellas plantas regeneradas.
THE EFFECT OF ORANGE RUST (Puccinia kuehnii) ON SUGAR YIELD IN SIX SUGAR CANE VARIETIES IN GUATEMALA

By

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KEYWORDS: Orange rust, Puccinia Kuehnii, Sugarcane, Yield Effects.

Abstract
A REPLICATED field trial was conducted to estimate the effect of orange rust (caused by Puccinia kuehnii) on yield in six sugarcane varieties in a plant cane crop in Guatemala. CP72-2086 is the leading variety in Guatemala constituting 57% of the crop in the 2007–08 harvest season. The other varieties (CG96-135, SP79-2233, CP88-1508, CP89-2143 and PR75-2002) showed symptoms of orange rust in September 2007 when the disease first appeared. The experimental design of the field trial was a split plot in a complete randomised block design where the main plot was variety and the sub plot fungicide treatment (treated with the fungicide Alto® (Cyproconazole) at a dose of 500 mL per ha) or untreated. The susceptible variety SP79-2233 was planted on each side of the trial and around individual plots as a natural P. kuehnii inoculum source. Orange rust severity in fungicide treated and untreated plots was recorded monthly from three to nine months crop age. Cane yield components (plant height, stalk diameter and stalk population) and cane weight per plot were used to estimate cane yield in tonnes of cane per hectare (TCH); sucrose concentration (Pol % cane) was also assessed at harvest. Yield losses were estimated using a regression of orange rust severity on yield (tonnes sugar per ha, TSH) for the variety CP72-2086. Data suggest that orange rust may reduce sugarcane yields in five of the six varieties. Losses in CP72-2086 were 7.67% (TCH), 8.61% (Pol % C) and 15.78% (TSH), with the regression equation y = 20.3 – 0.2×. The highest orange rust severity occurred at five to six months crop age in all varieties and symptoms were observed through to plant maturity.

Introduction
Until the year 2000, orange rust, caused by Puccinia kuehnii was of little economic importance worldwide but, in that year, an Australian epidemic caused losses estimated to be worth between 150 and 210 million Australian dollars (Braithwaite, 2005). The variety Q124 was the most widely planted in Queensland, occupying 45% of the total area, and it became susceptible to the disease. The orange rust epidemic was, in economic terms, the most important disease epidemic in the history of the Australian sugarcane industry (Braithwaite, 2005).

Pre-2007, orange rust was found only in countries such as Papua New Guinea, Indonesia, Philippines and Australia (south east Asia, Oceania areas) (Magarey et al., 2005). In June 2007, the disease was detected in Palm Beach County, Florida, USA, on the varieties CP80-1743 and CP72-2086 (Comstock et al., 2008) and this constituted the first report of the disease in the western Hemisphere. The variety CP72-2086 is the most important in Guatemala.
Orange rust was detected for the first time in Guatemala on September 7, 2007 (Ovalle et al., 2008) in a commercial field of the variety CP72-2086. This variety occupied 66% of the total area (210 000 ha) during the 2006–2007 harvest season.

As a first step to confirm the diagnosis, infected leaf samples were sent to the USDA-APHIS Systematic Mycology and Microbiology Laboratory in Beltsville, Maryland, for molecular and morphological examination.

The rust pathogen was confirmed as *P. kuehnii* in November 2007. The potential impact of orange rust on Guatemalan sugarcane crops was unknown at this time.

The purpose of this research was to determine the effect of orange rust on sugar yield in six commercial varieties that had shown disease symptoms.

**Materials and methods**

**Tested varieties**

The varieties evaluated were: CP72-2086, SP79-2233, CP88-1508, PR75-2002, CG96-135 and CP89-2143. The first four are major varieties in Guatemala and the last two are minor commercial varieties.

**Planting and handling in the field**

The experimental design of the field trial was a split plot in a complete randomised block design. The main plot was the variety and the sub plot was either treated or untreated with fungicide (Alto® 10 SL fungicide (Cyproconazole) used at a dosage of 500 mL per ha (Staier et al., 2003)). Applications began when the crop was two months of age, when pustules were first observed, and continued at 10 day intervals (nine applications) concluding when the crop was five months of age.

Small plots were five rows, 10 metres long and 1.5 m apart. The variety SP79-2233 (the most susceptible at the time) was planted in inoculum spreader rows, adjacent to each main plot and around the whole trial site. Crops was fertilised at recommended commercial rates (40.8, 60.9, 0.0 kg/ha NPK)

**Disease severity with time**

Orange rust disease severity was recorded at monthly intervals, from three to nine months crop age. Severity assessments were made on the top third of the seventh fully expanded leaf. One rating for each of the three central rows from each small plot (three leaves per plot), and one rating from each of the inoculum spreader rows were taken.

Each rating was identified by row to be able to match specific yield of each row with disease severity in that row (18 values for each variety). This enabled yield losses to be correlated with disease severity.

**Harvest**

The varieties were harvested at eleven months crop age (February, 2009) independent of optimum variety maturity and without ripener application.

Rows from each plot were harvested and weighed individually to estimate cane yield. Eighteen yield measurements were obtained for each variety (3 rows, 3 reps, treated / untreated) and were analysed using regression techniques.

At harvest five stalk samples from each small plot were analysed for sucrose concentration (Pol % cane).

**Measured variables**

The measured variables were cane weight per row to estimate cane yield in tonnes per hectare (TCH) and sugar concentration (Pol % cane) to estimate the derived parameter sugar yield in tonnes of sugar per hectare (TSH).

Cane yield components (stalk length, stalk diameter and stalk number/metre) were also recorded.
Data analysis

Analysis of variance was undertaken for TCH, Pol % cane, TSH, stalk length, stalk diameter and stalk population. For TCH, TSH, Pol % cane and cane yield components, “t” tests were undertaken to compare treatment x variety effects (CP72-2086, CG96-135 and SP79-2233).

Results and discussion

Figure 1 shows the severity of orange rust in inoculum spreader rows during crop growth. Relatively high disease severity occurred during the whole evaluation period. This suggests there was a high infection pressure on the test varieties within the trial.

The data suggest 25 percent leaf area was the maximum average severity observed from five to eight months age; however, in individual rows, up to 40 percent leaf area affected was recorded.

![Infection (%) on +7 leaf vs Age (Months after planting)](image)

Fig. 1—Severity of orange rust in spreader rows of the variety SP79-2233.

Despite the high infection pressure, fungicide application maintained lower disease severity (near zero) compared with plots without fungicide. When fungicide applications ceased (after five months crop age) disease levels rose in formerly treated plots (Figure 2).

The increase in rust severity in the fungicide treated plot may have reduced the differences between the two treatments.

The percent leaf area infected in these test appears to be less than occurred in the Australian epidemic where up to 70% of the third fully expanded leaf was affected (Magarey et al., 2001). Magarey et al. (2003) mentioned losses as high as 40% in central Queensland in the 2000 crop.

The authors suggest that the variation could be related to local weather and agronomic conditions at the sites and the same could be occurring with the Guatemalan test. Besides, differences in variety resistance should be considered.

Orange rust affected biomass (TCH) production in five out of six tested varieties, based on the difference in cane yield in plots with and without fungicide application (Table 1). However, the analysis of variance did not show significant treatment differences (Table 2).

The biggest effect of orange rust was in the variety CG96-135 with average losses of 18.09 TCH (12.25%). CG 96-135 had the largest variance value and, therefore, the biggest experimental data error. This variance caused no significant treatment differences in this variety.
The variety CP72-2086 showed a 7.67% decrease in cane yield (significant using a “t” test). Biomass differences for the rest of the varieties were not significant.

The smallest effect was seen with CP88-1508 where yield differences were 0.07 tonnes (0.05% of losses). PR75-2002 did not show a decrease in tonnage despite a higher orange rust incidence than CP89-2143 (Figures 3 and 5).

Average TCH in fungicide vs. non-treated plots was 140.78 and 136.52. Average losses associated with orange rust were 3.02%.
Table 1—Orange rust effect in tonnes of cane per hectare (TCH) on six commercial varieties in plant cane crop. Harvest season 2008–2009. Amazonas farm, Santa Ana Mill, Guatemala.

<table>
<thead>
<tr>
<th>Cane yield (TCH)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>With fungicide</td>
<td>Without fungicide</td>
</tr>
<tr>
<td>CG96-135</td>
<td>147.44</td>
</tr>
<tr>
<td>CP72-2086</td>
<td>127.77</td>
</tr>
<tr>
<td>SP79-2233</td>
<td>154.63</td>
</tr>
<tr>
<td>CP89-2143</td>
<td>126.49</td>
</tr>
<tr>
<td>CP88-1508</td>
<td>126.02</td>
</tr>
<tr>
<td>PR75-2002</td>
<td>162.35</td>
</tr>
<tr>
<td>Average</td>
<td>140.78</td>
</tr>
</tbody>
</table>

Table 2—Analysis of variance for tonnes of cane per hectare (TCH), of six varieties with and without fungicide application.

<table>
<thead>
<tr>
<th>S.V.</th>
<th>D.F</th>
<th>F value</th>
<th>Probability</th>
<th>Significance</th>
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</thead>
<tbody>
<tr>
<td>Replications</td>
<td>2</td>
<td>3.87</td>
<td>0.02</td>
<td>*</td>
</tr>
<tr>
<td>Varieties</td>
<td>5</td>
<td>28.25</td>
<td>0.0001</td>
<td>**</td>
</tr>
<tr>
<td>Rep x Var</td>
<td>10</td>
<td>0.52</td>
<td>0.87</td>
<td>N.S.</td>
</tr>
<tr>
<td>Treatments</td>
<td>1</td>
<td>1.31</td>
<td>0.25</td>
<td>N.S.</td>
</tr>
</tbody>
</table>

C.V. = 13.94

With five varieties there was a decrease in sugar content (Pol % cane) associated with orange rust (no fungicide application) (Table 3). The variety exhibiting the biggest decrease (8.61 percent) was CP72-2086 (significant “t” test). The exception was the variety CG96-135, which showed 12.97 percent more sugar in non-fungicide plots (also significant with the “t” test). There were no significant differences in Pol % cane for the six tested varieties.

Table 3—Orange rust effect on sugar concentration (Pol % cane) in six commercial varieties with and without fungicide application in the plant cane crop, 2008–2009 harvest season, Amazonas farm, Santa Ana Mill, Guatemala.

<table>
<thead>
<tr>
<th>Sugar concentration (Pol% cane)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>With fungicide</td>
<td>Without fungicide</td>
</tr>
<tr>
<td>CP72-2086</td>
<td>15.15</td>
</tr>
<tr>
<td>CP89-2143</td>
<td>15.46</td>
</tr>
<tr>
<td>CP88-1508</td>
<td>13.91</td>
</tr>
<tr>
<td>SP79-2233</td>
<td>14.76</td>
</tr>
<tr>
<td>PR75-2002</td>
<td>15.13</td>
</tr>
<tr>
<td>CG96-135</td>
<td>12.86</td>
</tr>
<tr>
<td>Average</td>
<td>14.55</td>
</tr>
</tbody>
</table>

The effect of fungicide application on the derived tonnes sugar per hectare is shown in Figure 3. Statistical analysis showed there were significant differences (10% level) in TSH for six varieties, with yields averaging 20.5 (fungicide) and 19.5 (no fungicide). However, for individual varieties, the biggest effect of orange rust on yield was with CP72-2086, where losses of 15.78% (TSH) were associated with orange rust; smaller losses were recorded with CP89-2143 and SP79-2233. It is important to take into account that fungicide application was only to five months crop
age, due to application difficulties in older crops. Figure 2 illustrates that, beyond five months, orange rust still occurred reaching more than 10% severity in CP72-2086 in nine-month old crops. The difference in TSH in the variety CP72-2086 was statistically significant (“t” test). The variety CG96-135 showed the smallest fungicide effect as it had a higher sucrose concentration in untreated plots (Table 3); the reason for this is unknown. This particular result should be further investigated in subsequent crop harvests to confirm the effect of orange rust on Pol % cane in this variety.

It is very important to note that the results above are from a field trial planted in an environment conducive to \textit{P. kuehnii}. In addition, orange rust spreader rows were planted with the purpose of promoting rust infection. To more realistically estimate sugar losses in commercial fields of CP72-2086, orange rust severity needs to be quantified in these specific fields and related to yield losses using the regression equation of Figure 4.
Statistical analysis showed no significant differences in cane yield components (stalk population, stalk length and stalk diameter). However, for stalk population, a difference was seen with the variety SP79-2233 (data not shown).

Disease severity over time in test varieties is shown in the Figure 5. In general, the maximum severity was recorded in crops of five to six months of age; after that severity tended to decrease.

Contrary to brown rust (*P. melanocephala*), orange rust infection continued to occur up to nine months crop age.

The variety with the highest disease severity throughout the season was SP79-2233, with 26.7 percent leaf area affected (on the +7 leaf) being the maximum level recorded. CP72-2086 (12.3 percent leaf area at five months of age) had the second highest level of disease.

![Graph showing orange rust severity with time in six commercial varieties.](image)

Fig. 5—Orange rust severity with time in six commercial varieties in the plant crop, 2008–2009 harvest season, Amazonas farm, Santa Ana Mill, Guatemala.

Conclusions

- Orange rust caused significant yield losses in the variety CP72-2086, the major commercial variety in Guatemala.
- Orange rust caused non-significant yield losses in four other varieties.
- Orange rust reached its highest severity at five and six months crop age in all of the tested varieties.
- Orange rust infection occurred in mature (up to nine months) crops.

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Also thanks to Ing. Ovidio Pérez and Ing. Adlai Meneses for the statistical analysis of data, both of CENGICAÑA senior staff and to Lic. Wendy de Cano and staff for the juice analysis at the CENGICAÑA’S Agronomic Laboratory.

Special thanks go to Dr. Jack Comstock, Research Plant Pathologist, USDA-ARS, Canal Point Experiment Station, for his exhaustive revision of the manuscript.
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EFFETS DE LA ROUILLE ORANGÉE (*PUCCINIA KUEHNII*) SUR LE RENDEMENT DE SIX VARIÉTÉS DE CANNE À SUCRE AU GUATEMALA

Par
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Résumé
Un essai à répétitions a été établi au champ pour estimer l’effet de la rouille orangée (causée par *Puccinia kuehnii*) sur le rendement en canne vierge de six variétés de la canne à sucre au Guatemala. La variété CP72-2086 est la variété principale au Guatemala et constituait 57% de la surface cultivée pendant la campagne 2007-08. Les autres variétés (CG96-135, SP79-2233, CP88-1508, CP89-2143 et PR75-2002) ont présenté des symptômes de la rouille orangée en septembre 2007 lors de l’apparition de la maladie. Le dispositif expérimental était un traitement à parcelles subdivisées en bloc de Fisher, le facteur principal étant la variété alors que le facteur secondaire était le traitement au fongicide (application d’Alto®, cyproconazole, à une dose de 500 mLha⁻¹) ou la parcelle non-traitée. La variété sensible SP79-2233 était plantée aux deux côtés de l’essai de même qu’autour de chaque parcelle comme source d’infection naturelle de *P. kuehnii*. La sévérité de la rouille orangée dans les parcelles traitées et non-traitées était évaluée tous les mois du troisième au neuvième mois du stade de poussée. La hauteur, le diamètre et la population de la tige de même que le poids de canne par parcelle étaient utilisés pour estimer le rendement à l’hectare (TCH). La concentration de saccharose (Pol % cane) était aussi recueillie à la récolte. Les pertes en rendement étaient estimées en adoptant une régression de sévérité de la rouille orangée en fonction du rendement (tonnes sucre à l’hectare, TSH) pour la variété CP72-2086. Les données indiquent
EFECTO DE LA ROYANA NARANJA (*Puccinia kuehnii*) EN EL RENDIMIENTO DE AZÚCAR EN SEIS VARIEDADES DE CAÑA DE AZÚCAR EN GUATEMALA

Por

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Resumen

SE EFECTUÓ un experimento de campo para estimar el efecto de la roya naranja (causada por *Puccinia kuehnii*) sobre el rendimiento de azúcar en seis variedades en caña planta en Guatemala.

La variedad CP72-2086 es la más importante en Guatemala y ocupó el 57% del área sembrada en la zafra 2007-08. Las otras variedades evaluadas (CG96-135, SP79-2233, CP88-1508, CP89-2143 y PR75-2002) son variedades comerciales que mostraron síntomas de roya naranja en septiembre de 2007 cuando la enfermedad se presentó en Guatemala. En el experimento de campo se utilizó un diseño experimental en Bloques completos al azar con arreglo en parcelas divididas, en donde la parcela grande fue variedad y la sub parcela fue tratamiento con fungicida (aplicaciones del fungicida Alto® (Cyproconazole) en dosis de 500 ml por hectárea) y sin aplicaciones. En cada lado del experimento y alrededor de las parcelas individuales se sembró la variedad susceptible SP79-2233 como fuente de inóculo natural de *P. kuehnii*. Se registró mensualmente la severidad de la roya naranja en las parcelas con y sin tratamiento con fungicida desde los tres hasta los nueve meses de edad del cultivo. Se utilizó los componentes de rendimiento de caña (altura de planta, diámetro de tallos y población) y el peso de caña por parcela para estimar el rendimiento de caña por hectárea (TCH), también se evaluó la concentración de azúcar (Pol % caña) al momento de la cosecha. Las pérdidas en rendimiento de azúcar se estimaron haciendo análisis de regresión entre severidad de roya naranja y rendimiento (toneladas de azúcar por hectárea, TAH) para la variedad CP72-2086. La información sugiere que la roya naranja puede reducir los rendimientos de azúcar en cinco de las seis variedades evaluadas. Las pérdidas en la variedad CP72-2086 fueron 7.67% (TCH), 8.61% (Pol % caña) y 15.78% (TAH), y la ecuación de regresión es y = 20.3 − 0.2x. La severidad mayor de roya naranja ocurrió entre cinco y seis meses de edad del cultivo en todas las variedades y se observaron síntomas de la enfermedad hasta la madurez de la planta.
ADVANCES AND CHALLENGES IN SUGARCANE BIOTECHNOLOGY AND PLANT PATHOLOGY: A REVIEW OF THE IX PLANT PATHOLOGY WORKSHOP AND VI MOLECULAR BIOLOGY WORKSHOP

By

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KEYWORDS: Diseases, Plant Resistance, Genetic Mapping, Molecular Characterisation, Transgenics.

Abstract

For the second time, the International Society of Sugar Cane Technologists (ISSCT) pathology and molecular biology workshops were jointly held, from 23–27 June 2008 in Cali, Colombia. The meeting was hosted by CENICAÑA and organised by Jorge I. Victoria and Jershon López-Gerena. The response of participants was positive with 44 delegates representing 15 countries attending. Thirty seven oral presentations and ten posters covering a wide range of topics including molecular characterisation of yeasts, insect pests and pathogens, genetic transformation of sugarcane, molecular markers, genetic mapping, pathogen variability, disease diagnosis, plant resistance and disease epidemiology among others were presented. The workshop also provided the opportunity to listen to three plenary talks on biofuel production, transgenics and nutritional improvements in food crops through genomics. A special session was devoted to orange rust, a newly introduced disease in Florida and in Central America. Following the technical sessions, site visits were organised during two days to sugar mills, commercial fields, plots with transgenic sugarcane, and laboratories at CENICAÑA. The experience of having joint-section meetings proved very useful with excellent interaction among participants.

Introduction

The ISSCT IX Pathology Workshop and VI Molecular Biology Workshop were organised jointly in 2008. The workshops were hosted by the Colombian Sugarcane Research Centre (CENICAÑA) from 23–27 June 2008 at the Radisson Royal Hotel in Cali, Colombia. It was organised by Drs Jorge I. Victoria and Jershon López-Gerena. The Workshops were well attended by 44 participants, with 39 of them coming from overseas – Argentina (4), Australia (4), Brazil (3), Ecuador (1), France (3), Guadeloupe (2), Guatemala (2), India (2), Mauritius (2), Nicaragua (2), Panama (1), South Africa (2), USA (9), Venezuela (1) and Zimbabwe (1) – and 5 from Colombia.
Apart from three plenary talks on biofuel production in Colombia, transgenics and the role of genomics to improve nutrition in food crops, 37 verbal and 10 poster presentations were made during 11 sessions. The topics covered during the workshop were diverse. Site visits were organised during two days to sugar mills, commercial fields, plots with transgenic sugarcane, and laboratories at CENICAÑA.

**Molecular characterisation of yeasts, insect pests and pathogens**

In Colombia, ethanol production within the sugar industry is rapidly expanding, and is being driven primarily by price regulation and tax incentives from government. Although production is based on technology imported from India, efforts are being made on several fronts to adapt the technology to suit local conditions. Research focused on the isolation of wild yeast strains that have the potential to out-perform commercial yeasts. Biochemical and molecular characterisation of 18 isolates revealed that 10 of them were *Saccharomyces* and were capable of fermentative respiration to produce ethanol. All of the ethanol-producing isolates could tolerate ethanol concentrations of 12% (v/v) and were at least as efficient as commercial strains.

The Colombian sugar industry has a long and proud history of successful biocontrol of sugarcane pests and the insect vectors of pathogens. A strategy was reported to reduce the negative impact of the yellow sugarcane aphid (*Sipha flava*), which reportedly reduces sugar yield (tonnes sucrose/ha) by up to 52%. Currently, the effects of this pest are minimised by insecticide application, host plant resistance and natural predation. Attempts at biocontrol have been made through the introduction of commercially reared North American lacewings (*Chrysoperla* spp.), but release results were erratic and difficult to interpret. Consequently, researchers at CENICAÑA are searching for local lacewings that may serve as more effective biocontrol agents of the aphid. Molecular technologies were used for the analysis of the lacewing phylogeny and 11 chrysopid morphotypes have been found. These findings will serve as the foundation for the development of a biocontrol mechanism against the yellow sugarcane aphid.

A molecular and morphological diversity study based on the sequence of the mitochondrial cytochrome oxidase gene, *COII*, from 108 borer specimens collected along the Cauca Valley, in Colombia, was carried out in 2005 to determine possible new races of the three borer species in the region: *Diatraea saccharalis*, *D. indigenella*, and *Blastobasis gramineae* that may explain recent borer population increases in the region. *D. saccharalis* was found to be the main species behind the outbreak, and there were no new races that explained the recent borer outbreak, according to genetic differentiation indices based on PCR-RFLP and sequence of a *COII* gene fragment. Changes in climate or agricultural practices may explain the outbreak. A survey in 2006 indicated that the borer population has decreased after control practices were further implemented.

**Genetically modified sugarcane**

In Argentina, regulatory framework governing the commercial release of genetically modified (GM) crops encompasses both food safety and environmental issues. Concern exists over the potential of GM crops becoming weeds or crossing with wild species that have the potential to become weeds. As *Saccharum spontaneum* exists as naturalised populations in Argentina, consideration of the potential for transgene spread from GM *Saccharum* spp. hybrid crops is essential. The low temperatures (10–12ºC) experienced in Argentina in the period prior to anther opening (June and July) were believed sufficient to suppress male fertility. However, it was revealed that, during June to August 2006, fertile sugarcane pollen was detectable in the northern regions of the Argentinean industry (between S 23°16’ and S 24°50’), although prevalence decreased southwards, such that no fertile pollen was detected between S 26°30’ and S 27°55’. The unexpectedly high pollen fertility encountered in the northern regions was ascribed to unusually warm winter conditions. It is important to note that final interpretation of these observations and the impact that they may have on the assessment of the risk of transgene spread in Argentina will require assessment of pollen longevity, distance of dispersal and, ultimately, seed viability.
Many institutes involved in GM sugarcane research are seeking ways to simplify and speed-up the transformation process, as well as to reduce somaclonal variation that sometimes results from tissue culture. Efforts to reduce time in culture, viz. through imposition of a 1–2 week post-bombardment callus induction period where selection was restricted to the regeneration phase, resulted in plants with chimaeric phenotypes. Researchers at Chacra Experimental Agricola Station, in Argentina, proposed that insufficient selective growth of transgenic cells in the absence of a callus selection phase yields heterogeneous masses of both transformed cells that develop into chimaeric embryos, which regenerate under non-stringent geneticin selection protocols. That group aims to further refine minimal culture and selection requirements, which will reduce or eliminate chimaeras.

In Brazil an attempt was made to evaluate stress-inducible production of proline in transgenic sugarcane. Researchers expressed into sugarcane the heterologous P5CS gene (for proline biosynthesis) from the drought resistant bean, *Vigna angustifolia*, under the control of the synthetic stress-induced AIPC promoter. A series of transgenic events with 1–4 insertions was generated and, upon drought stress, the proline content was on average 2.5 times higher than in the controls, and this led to good drought tolerance. It was determined that the mode of action was not due to osmotic adjustment but, instead, related to a component of oxidative defence system.

In Australia, *Agrobacterium*-mediated and biolistic methods for transformation of sugarcane were compared. Several parameters were tested in transient assays to optimise *Agrobacterium*-mediated transformation of embryogenic callus of the variety Q117. *Agrobacterium* strains LBA4404 and AGL1, and a pCambia vector with GUS as the reporter gene under the control of the CaMV 35S promoter were used. Vacuum infiltration worked well for transient expression. Further optimisation was done with AGL1 and it was found that dilution of the *Agrobacterium* cultures to an O.D. of 0.4 was best as was a 4-day co-cultivation period on EM3 medium. However, no transgenic plant was regenerated, and constructs using the maize Ubi 1 promoter rather than the CaMV35S promoter were produced and generated over 200 plants. Most of the plants had only 1 or 2 insertion events. In a comparison between *Agrobacterium* and biolistic methods for expression levels, the biolistic approach led to much higher expression levels, but there was no correlation with copy number.

Molecular markers and genetic mapping

Microsatellite primers were used to DNA fingerprint varieties in Colombia and in USA, and DNA databases are being built. The intended use of these databases includes identification of mislabelled parental clones, as molecular descriptors for newly released varieties determine genetic relatedness of elite clones, assessing the quality of crosses, and identifying F1 hybrids from crosses with wild germplasm.

In South Africa, progress was reported to identify the key control steps in sucrose accumulation in sugarcane. Early work focused on changes in gene expression, biochemistry, and physiology occurring along internode maturation in one or a few varieties with different sucrose accumulation capacities. Gene expression studies moved to focus on key metabolic pathways identified by subtractive DNA libraries and boutique arrays. A small set of candidates was identified, and some of them studied on transgenic plants grown in the field. Currently, physiological evidence points to source-sink communication as crucial to sucrose metabolism, where feedback inhibition between sucrose concentration in the culm and leaf photosynthesis limits further accumulation of sucrose. New candidate genes will be tested via simple and stacked transgenic approaches to attempt unlocking the key to sucrose accumulation.

Also in South Africa, the potential of combining two relatively new PCR-based marker systems, Targeted Region Amplified Polymorphism (TRAP) and Motif-Directed Profiling (MDP) into a high-throughput hybrid system to generate polymorphic markers around targeted candidate gene sequences for smut resistance, was explored.
In Colombia, QTLs for sugar content and biomass components were identified in a population of 300 individuals from a cross between a high sugar content cultivar and a low sucrose cultivar.

In Mauritius, efforts were deployed to detect QTLs for yellow spot disease resistance. The foundation of the study was a bi-parental cross between a resistant and a susceptible parent, which generated 227 progeny with a segregation pattern for yellow spot infection suggestive of monogenic dominant inheritance (3:1). A genetic map of variety M 134/75 was constructed using 764 single-dose polymorphisms assigned to 102 linkage groups, each of which contained at least two markers in coupling. QTL analysis by means of QTL-CARTOGRAPHER v1.17d and MAPMAKER/QTL v1.1 identified a major QTL located on Linkage Group 87, flanked by an AFLP and SSR marker.

Work from CIRAD in France provided evidence of a major dominant gene *Brul*, conferring brown rust resistance, identified in cultivar R570 to confer resistance to eight isolates from Brazil, Colombia, Zimbabwe, USA (Florida), Réunion and Guadeloupe. The target haplotype map encompasses 15 markers that co-segregate with *Brul* and markers, and the physical map encompassing 16 BAC clones was discussed. The markers surrounding *Brul* in R570 were surveyed in nearly 400 international sugarcane cultivars and were also phenotyped for rust resistance in Réunion and Guadeloupe islands and found that *Brul* was present in most of the resistant cultivars. Only 7% of them did not display the *Brul* haplotype, and thus they represent alternative sources of resistance to the rust pathogen. The PCR marker in perfect linkage disequilibrium with *Brul* can also be used as a diagnostic for the presence of *Brul* in experimental sugarcane cultivars.

Preliminary results regarding tagging alleles involved in *X. albilineans* leaf infection resistance were reported by Hoarau and collaborators from CIRAD, Guadeloupe. The authors used a large unstructured population of 198 sugarcane clones that was recorded for severity of leaf symptoms, and 700 polymorphic AFLP markers. A set of six markers explained 31% of the total phenotypic variation in necrotic leaf symptom intensity. This first insight into *X. albilineans* leaf colonisation resistance needs to be continued with additional markers to further tag sugarcane alleles involved in this resistance.

**Leaf scald disease**

Results of a proteomics approach to study sugarcane’s reaction to infection by *Xanthomonas albilineans* were presented by researchers from Lousiana State University, USA. They used a differential protein expression analysis based on 2-dimensional electrophoresis using one resistant (Ho 95-988) and one susceptible (CP 89-846) sugarcane variety and compared protein profiles from infected and non-infected plants. Proteins that were differentially up and down-regulated in the susceptible and resistant varieties were found.

Leaf surface colonisation and stalk infection by *Xanthomonas albilineans* of sugarcane was determined in varieties grown under high rainfall conditions in Guadeloupe. The *X. albilineans* colonisation of sugarcane leaf surface after aerial spread of the pathogen varied according to the host cultivar. The stalks of two (out of 8) sugarcane varieties that exhibited the highest leaf surface populations were also the most infected by *X. albilineans*. Additionally, severity of leaf necrotic symptoms was correlated with intensity of leaf colonisation. It was also concluded that resistance of sugarcane to leaf scald appears to be controlled by several mechanisms, from leaf surface colonisation to stalk colonisation. It was noted that only a few reports of aerial spread of *X. albilineans* have been reported in Florida, USA, Guadeloupe and Mauritius and that possible recovery from stalk infection from one crop cycle to another could occur. The importance of high temperature on leaf scald symptom progress and severity was discussed.

**Viruses**

The first large-scale survey of the causal agent of sugarcane mosaic in Argentina and neighbouring regions was made. This survey was undertaken to determine the mosaic virus
population present in Argentina and to improve control of mosaic with transgenic plants. Five hundred and twenty two plants showing mosaic symptoms were analysed by RT-PCR, and leaves were sampled from 111 sites and 106 sugarcane varieties. The majority (95%) of samples from Argentina were infected by Sugarcane mosaic virus (SCMV). Sorghum mosaic virus (SrMV) was found in only 1.5% of the samples. SCMV was present in the 35 samples from Bolivia and Uruguay. Both SCMV and SrMV were detected in symptomatic plants from Paraguay, but only a few samples originated from this country. Some samples (4.4%) from Argentina tested negative for SCMV and SrMV and the virus present in these samples remains to be determined.

Mike Grisham described the virus strains causing sugarcane mosaic symptoms in Louisiana and Florida, USA. No SCMV was found in Louisiana and no SrMV in Florida. In Louisiana, strains of SrMV present were: SrMV-I, 66%, SrMV-H, 14% and SrMV-M 6%. In 7% of samples, RFLP analysis indicated that the strain was different from strains H, I and M. Furthermore, an unknown strain was present in 10% of samples showing mosaic symptoms, suggesting the presence of another virus causing mosaic in Louisiana. In Florida, only SCMV-E was observed in symptomatic samples. No Sugarcane streak mosaic virus (SCSMV) was detected in samples from both States. The results of this study showed that there has been a shift in the strain profile in Louisiana since 1990–1995, when SrMV-H was most abundant (90%), followed by SrMV-I (10%) and SrMV-M (3–5%). The difference in the strain distribution of Florida and Louisiana could not be explained. It was felt that there is a need to investigate the genetic diversity of SCMV internationally.

In Mauritius, a sensitive detection technique for Sugarcane yellow leaf virus (SCYLV) using real-time fluorescent Taqman® RT-PCR assay was developed. This was found to be 100x more sensitive than conventional RT-PCR. This method allowed the simultaneous detection of the virus and an internal sugarcane positive control. The internal positive control increases the reliability of the test by eliminating false negatives. Also, genetic diversity studies using a two-step RT-PCR showed the presence of the REU genotype of the virus, predominantly, as well as CUB and BRA-PER genotypes in the Mauritian sugarcane germplasm collection. Mixed infection of REU with either CUB or BRA-PER genotype was also present.

In Mauritius an island-wide survey for the presence of SCLYV in 22 commercial cultivars revealed that 58.8% of the over 3000 samples were infected with the virus. The incidence of infection ranged from zero in variety M 1176/77 to 100% in variety R 579. Severe symptoms were observed in varieties M 695/69, M 52/78, M 387/85, M 1186/86, M 1400/86, M 2004/88, M 703/89, M 2593/92, R 570, R 573, and R 575, but did not correlate closely with the presence of the virus. The presence of the aphid vector, Melanaphis sacchari was low and the spread of the virus was thought to be primarily by seed cane.

The incidence of SCYLV was compared in the two geographically close islands of Guadeloupe and Martinique. Infection was lower in Guadeloupe, although the vector population and cultivated varieties were the same. In Guadeloupe, the REU genotype predominated over BRA-PER. In Martinique, BRA-PER was more important and sometimes with mixed infection of REU. The differences observed between the two islands suggest the occurrence of local effects and interactions.

In Ecuador, from 2001 to 2005, the incidence of SCYLV increased dramatically. Yield trials using disease-free plants obtained via meristem culture had 20% more cane production and 36% more tonnes sucrose per hectare (TSH) than infected plants. Plants treated with insecticides increased yields compared to untreated plants. The best method of control was a combination of using virus-free plants derived from meristem culture along with systemic insecticides.

Studies at CIRAD indicated that, of the four different genotypes of SCYLV, diagnosis of the CUB genotype was the most difficult with the available primers. New primers were developed that allowed detection of all isolates of CUB genotype. The distribution of CUB isolates is being investigated using the newly developed primers.
Evidence was presented by research carried out in Australia that the causal agent of Ramu stunt disease is a virus. Viral preparations from infected leaves showed a 36-kDa protein to be consistently detected and isometric viral particles were observed from the infected cultivar Ragnar. Sequences of RNA with homology to viral RNA-dependent RNA polymerase have been cloned. A test that can detect a 1 kb RT-PCR product in leaf RNA extracts and the insect vector has been developed for the disease.

Phytoplasmas

In India, nucleotide sequence analysis of the 16SrRNA gene and the 16S/23S rDNA established that sugarcane grassy shoot (SCGS) phytoplasma is closely related to that of sugarcane white leaf (SCWL) disease. The two sugarcane phytoplasmas share a 97.5–98.8% homology with respect to their 16S rDNA sequences. SCGS phytoplasma was also found to belong to the rice yellow dwarf phytoplasma group. In contrast, sorghum grassy shoot phytoplasma was more distantly related to SCGS. Nested PCR was required to reliably detect SCGS. Resistance to the disease was found to be present among cultivated varieties.

The occurrence of sugarcane yellows phytoplasma (SCYP) associated with yellow leaf syndrome (YLS) exhibiting symptoms of sugarcane leaf yellows and yellowing of midribs was also reported in India. A phytoplasma characteristic ~0.840 kb rDNA PCR product was amplified from DNAs of all infected sugarcane leaf samples but not in healthy sugarcane plants tested using phytoplasma universal primer pairs P1/P7 and fU3/rU5. RFLP analysis of PCR products with Hae III and Hha I endonuclease generated fragment profiles that were identical for all the samples. The 16S rRNA sequence of the Indian SCYP isolate (EU170474) showed the closest identity (99%) with that of SCYP isolate in Cuba identified in Macroptilium lathyroides (AY725233) and other grasses like Cynodon dactylon (AB052871), Conyza canadensis (AY 725231) and Sorghum halapense (AY 725232), which belong to 16SrXII (Stolbur group). This was the first report of 16SrXII group phytoplasma affecting sugarcane in India.

Smut

With the introduction of sugarcane smut (Ustilago scitaminea) into Queensland in Australia in 2006, a smut-screening program started there, as it was clear that the disease could not be eradicated. The proportion of smut-resistant clones increased from 0.4% in 2000 to 52% in 2007. Spore traps were used to detect sugarcane smut spores in areas prior to the visual detection of the disease. Initially, smut spores were identified by visual inspection of the collection tapes. Because of dirt particles and other spores, visual confirmation was slow and difficult. A DNA extraction and PCR-based assay method was developed that allowed easy confirmation of the presence of smut spores.

In several sugarcane growing areas, smut was identified on the tape samples prior to the actual visual observation of smut whips in the same areas. The confirmation of the aerial spread of smut into areas where smut had not been observed helped to influence growers to shift to smut-resistant varieties.

Although smut spores are a major method of spread of smut over long distances, their survival is influenced by temperature and moisture. Studies showed that spores germinated under temperatures ranging from 12 to 36°C. Under moist conditions, smut spores survived only for short time periods (2–3 months) in the soil, sugarcane trash and in the laboratory. However, survival of smut spores under dry conditions is greatly extended. Smut spores will survive for up to 6 months on machinery and on cotton clothing, and these mechanisms could, in theory, spread the pathogen.

Rusts

The epidemiology of brown rust (Puccinia melanocephala) in Louisiana was discussed with major emphasis on yield losses, resistance and fungicidal control. The magnitude of demonstrated losses strongly suggested that the application of fungicides be explored. Strobilurin fungicides were found more effective than triazole fungicides in reducing rust severity and yield losses. However,
combinations of these two fungicide types were superior. Two applications of fungicides can provide better economic benefits against rust incidence and infection severity. However, further research is required for the time and mode of application of fungicides against rust infection for maximum economic benefit, and research is in progress. Until now, host resistance is the most desirable control method of brown rust in Louisiana, but adaptability of the pathogen and problems in regular replacement of commercial sugarcane varieties in sugarcane are the major hurdles.

In Colombia, brown rust severity has increased on resistant varieties (CC 85-92, CC 84-75, CC 93-3895, CC 92-2804 and CC 94-5827) during the last 2 years. No molecular variation in the rust pathogen was observed using ITS 1F/ITS4 primers and restriction enzymes (ALU I and Hinf I). More genomic regions in the rust pathogen are being evaluated. The reason for the increased severity of rust symptoms is unknown. Based on microscopic evaluation, only the brown rust pathogen was present. Based on the differences in rust symptom expression, it is assumed that a new race may be present.

Until 2007, orange rust (Puccinia kuehnii) had been observed only in Australia, Philippines, Indonesia and Papua New Guinea. In Australia it was considered as a minor disease until an epidemic occurred in 2000 and caused millions of Australian dollar losses to the sugar industry there. Then, in 2007, orange rust was confirmed in Florida (USA), Costa Rica, Guatemala, Nicaragua and Panama. In Guatemala, the presence of sugarcane orange rust (Puccinia kuehnii) was detected in September 2007. The disease was found to be widespread on CP 72-2086 with low severity of symptoms.

Concerns were expressed over the appearance of the disease in the American continent, and ways and means to counteract the disease were discussed including the replacement of susceptible commercial varieties and the identification of resistant parents for crosses.

New techniques

The usefulness of tools applied in precision agriculture to plant pathology was explained by the group of researchers from Louisiana, USA. The influence of environmental conditions and cultural practices on the incidence of brown rust was investigated. Infection was found to be positively correlated with soil properties, particularly the levels of phosphorus and sulfur. It was deduced that excess fertiliser applications could bring about a higher rust incidence and thereby negatively affect sucrose and cane yields. Remote sensing using a fibre optic spectrometer was utilised to determine leaf infection by SCMV or SrMV. Analysis of mild and severe SCMV leaf reflectance measurements were correctly classified in 75 and 68% of the cases, respectively. Leaves infected by SCYLV were correctly identified 77% of the time.

Conclusion

The workshop was very successful and the quality of work presented by participants was high. It is evident that a number of important and significant advances have been made recently both in the field of sugarcane pathology and biotechnology since the last workshops. The ISSCT sponsored workshops have played a major role in advancing the knowledge, cooperation and technology of sugarcane scientists. The attendees of the Workshop thank Drs Victoria and López-Gerena and CENICANA for hosting this excellent Workshop.
LES AVANCÉES ET LES DÉFIS EN BIOTECHNOLOGIE ET PATHOLOGIE DE LA CANNE À SUCRE: UNE REVUE DU IX ATELIER DE PATHOLOGIE ET DU VI ATELIER DE BIOLOGIE MOLÉCULAIRE

Par

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MOTS-CLÉS: Maladies, Résistance des Plantes, Cartographie Génétique, Caractérisation Moléculaire, Transgénique.

Résumé

LES ATELIERS de travail de Pathologie et de Biologie Moléculaire de l’International Society of Sugar Cane Technologists (ISSCT) ont été tenus conjointement pour la deuxième fois du 23-27 juin 2008 à Cali, Colombie. La réunion a été parrainée par le CENICAÑA et organisée par Jorge I. Victoria et Jershon López-Gerena. La participation fut très positive avec la présence de 44 délégués de 15 pays. Trente-sept présentations orales et dix posters, couvrant un large éventail de sujets, tels que la caractérisation moléculaire des levures, les ravageurs et les pathogènes, la transformation génétique de la canne, les marqueurs moléculaires, la cartographie génétique, la variabilité des pathogènes, le diagnostic des maladies, la résistance de la plante et l’épidémiologie des maladies ont été abordés. Trois discours sur la production des biocarburants, la transgénèse et le génomique de l’amélioration nutritionnelle des cultures vivrières furent prononcés pendant les sessions plénières. Une session spéciale a été consacrée à la rouille orangée, une maladie nouvellement apparue en Floride et en Amérique Centrale. Pendant deux jours, les participants eurent aussi l’occasion de visiter des sucreries, des champs industriels, des parcelles de canne transgéniques ainsi que les laboratoires de CENICAÑA. Cette réunion conjointe s’est avérée fruitueuse et elle a donné lieu à une excellente interaction entre les participants.
AVANCES Y RETOS EN LA BIOTECNOLOGÍA Y PATOLOGÍA DE LA CAÑA DE AZÚCAR: UNA REVISIÓN DEL TALLER IX DE PATOLOGÍA Y VI DE BIOLOGÍA MOLECULAR


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PALABRAS CLAVES: Enfermedades, Resistencia, Mapeo Genético, Caracterización Molecular, Transgénicos.

Resumen

POR SEGUNDA VEZ, la Sociedad Internacional de Tecnólogos de la Caña de Azúcar (ISSCT) se celebraron conjuntamente los talleres de Patología y de Biología Molecular, entre el 23–27 junio de 2008 en Cali, Colombia. La reunión fue organizada por CENICAÑA bajo la dirección de Jorge I. Victoria y Jershon López-Gerena. La respuesta de los participantes fue positiva, con 44 delegados en representación de 15 países asistentes. Treinta y siete presentaciones orales y diez carteles que cubrieron una amplia gama de temas, se presentaron, incluyendo la caracterización molecular de levaduras, insectos plagas y patógenos, la transformación genética de la caña de azúcar, marcadores moleculares, mapeo genético, la variabilidad del patógeno, el diagnóstico de enfermedades, resistencia de las plantas y la epidemiología de la enfermedad, entre otros. El taller también brindó la oportunidad de escuchar tres conferencias plenarias sobre la producción de biocombustibles, los transgénicos y las mejoras nutricionales en los cultivos de alimentos a través de la genómica. Una sesión especial fue dedicada a la roya de naranja, una enfermedad de reciente introducción en la Florida y en América Central. Tras las sesiones técnicas, se organizaron visitas durante dos días en los ingenios azucareros, los campos comerciales, terrenos con caña de azúcar transgénica, y los laboratorios de Cenicaña. La experiencia de tener reuniones y sesiones conjuntas nuevamente demostró ser muy útil por la excelente interacción entre los participantes.
SUGARCANE RUSTS IN FLORIDA

By

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KEYWORDS: Sugarcane Brown Rust, Orange Rust, Puccinia melanocephala, P. kuehniii.

Abstract
SUGARCANE orange rust symptoms were first observed in Florida in June 2007 on cultivar CP 80-1743. The causal agent, Puccinia kuehniii, was subsequently verified morphologically and molecularly constituting the first confirmed report of sugarcane orange rust in the Western Hemisphere. Orange rust was distributed throughout the entire Florida sugarcane industry, primarily on cultivars CP 80-1743 and CP 72-2086. The objective of this research was to evaluate the reaction of the commercial cultivars to both sugarcane brown and orange rusts and to assess their effect on the CP-cultivar development program in Florida. The rust reactions of several widely grown commercial cultivars, newly released cultivars and clones in the selection program, parental clones and CP historical clones were determined in order to develop a suitable resistance strategy to address the new incursion of orange rust. Changes in the program to increase the level of rust-resistant progeny are detailed.

Introduction
Sugarcane brown and orange rusts are the two primary rust diseases of sugarcane (Magarey, 2000; Raid and Comstock, 2000). Both sugarcane rusts have had a significant impact on the Florida sugarcane industry. The development of sustained resistance to sugarcane brown rust caused by Puccinia melanocephala has not always been successful.

The brown rust pathogen, P. melanocephala, was unable to develop on a number of cultivars when they were released but they subsequently show severe symptoms. After several years of commercial production, brown rust developed on CP 70-1133, CP 72-1210 and CP 78-1247 rendering them unsuitable for further cropping. Additionally, CP 78-1628, a major cultivar on sand soils, has also become susceptible to brown rust since being released in 1991 (Tai et al., 1991).

During the clonal selection program, rust reactions were traditionally determined solely on natural infection of clones in field plots. Unfortunately, this can lead to inconsistent results due to variability in disease levels between locations resulting in an inadequate rust resistance evaluation. Another possible reason for the change in resistance rating may be pathogen variation.

There have been reports of pathogenic races of P. melanocephala in Florida (Shine et al., 2005) and P. kuehniii in Australia (Braithwaite, 2005). Some stages of the Canal Point cultivar development program are of necessity planted at a time of the year that does not favour rust infection in these canes (in the March through mid-May period when brown rust is most prevalent).

In June 2007, orange rust caused by P. kuehniii was detected in Florida (Comstock et al., 2008). Orange rust was initially recognised because of the unusual amount of rust seen in the previously rust-
resistant cultivar CP 80-1743. On close examination, the rust pustules were lighter and more orange in colour than brown rust pustules. Furthermore, the urediniospores had a prominent apical thickening instead of the uniform walls observed in *P. melanocephala*.

These morphological characteristics, together with molecular sequencing information, confirmed the pathogen as *Puccinia kuehnii*, the orange rust pathogen (Comstock *et al.*, 2008). Subsequently, orange rust was confirmed in Guatemala, Costa Rica, Nicaragua, El Salvador, Mexico and Panama (Ovalle *et al.*, 2008; Chavarría *et al.*, 2009; Flores *et al.*, 2009). In Florida, orange rust associated yield losses in crops of CP 80-1743 were estimated at 40% in 2008 (Richard Raid, Pers. Comm.).

This is similar to losses reported in the Central district of Australia in the 1999-series plant crop (Magarey *et al.*, 2008). Orange rust has reduced yields of CP 72-2086 in some locations in Central America where environmental conditions are conducive for disease development. This is particularly true in the southern region of Costa Rica and the lower elevations of Guatemala, both warm humid areas. Losses of 8% were estimated in Guatemala on CP 72-2086 (W. Ovalle, Pers. Comm.).

CP 80-1743 occupied 22.8% of the industry acreage in Florida in 2007 and up to 40% in some sections of the industry. Initial surveys indicated that orange rust was distributed throughout the entire industry (where CP 80-1743 or other susceptible clones were grown). Yield losses dictated the need to withdraw CP 80-1743 from production. Germplasm in the Canal Point (CP) Cultivar Development Program was impacted, as a large portion of parental clones were susceptible, as too were a portion of the clones in the selection program and these too had to be eliminated.

A whorl inoculation technique was recently developed and is being used to determine rust reactions in Florida (Sood *et al.*, 2009). This procedure allows individual plants to be inoculated in the field with specifically selected inoculum. When windblown inocula are limited, screens can be completed using stored spores. Large numbers of clones can be screened using limited labour. Ratings are applied based on the type and severity of pustule development.

The objectives of this paper are 1) to provide a brief history of the sugarcane orange rust outbreak in Florida, 2) present the impact of sugarcane orange rust on the commercial cultivars and parental clones, 3) to present resistance data on clones in the CP-Cultivar Development Program and compare the ratings of individual clones as they are advanced from one stage to the next.

**Materials and methods**

**Rust rating scales**

Both sugarcane brown and orange rusts were rated using two different rating scales depending on whether the plants were naturally infected in the field or were inoculated using a whorl inoculation technique under field conditions.

The natural infection scale is based on the presence and number of pustules using a 5 point scale as follows: 0 = no symptoms; 1 = one or a very few pustules; 2 = more than a few pustules; 3 = numerous pustules both on the lower leaves and to a lesser extent on the upper leaves and 4 = severe rust development with extensive coalescing of pustules and leaf necrosis due to rust. Ratings 0 and 1 are classified as resistant reactions, a rating of 2 is moderately susceptible and 3 and 4 are susceptible.

Field plot ratings require rust assessments on check varieties to validate the ratings. The artificial inoculation scale used to determine rust reactions after whorl inoculation is based entirely on pustule formation and presence and amount of sporulation occurring using the following scale: 1 = no visible symptoms; 2 = small yellow flecking with no sporulation and no pustule development; 3 = small pustules with limited urediniospore development (some sporulation); and 4 = pustules with abundant sporulation. Ratings 1 and 2 are resistant and ratings 3 and 4 are respectively, moderately susceptible and susceptible.
Whorl inoculation procedure

A whorl inoculation procedure was used to inoculate 3 to 6 month old field plants as previously described (Sood et al., 2009). Briefly, inoculations are made using an automatic pipetter by placing 0.5 to 1.0 mL urediniospore suspension (10^4 urediniospores per mL for *P. kuehnii* and 10^5 urediniospores per mL for *P. melanocephala*) into the spindle leaf whorl of individual stalks. Inoculated stalks are marked by cutting off one third of the leaf tips to identify what leaves to evaluate. Inoculations are made at 7:30 am to 9:00 am when the plants have dew on their leaves and prior to the peak temperature of the day. There were three inoculated plants in a single plot for Stage II clones, six inoculated plants for Stage III clones (3 plants in two plots) and 12 plants for Stage III increase and Stage IV clones (3 plants in 4 plots). Rust reaction ratings were made 4 weeks after inoculation using the whorl inoculation scale described above and the data were averaged.

Rust reactions based on natural infection

Rust reactions of both brown and orange rust (since 2007) reactions were based on natural infection using the 0 to 4 rating scale described above. The following germplasm was rated for their rust reactions: commercial cultivars, released cultivars (with < 1% of the acreage), clones in the program to increase seedcane for multiplication, clones in all stages of the selection program including Stage II (single location, unreplicated), Stage III (four locations), and Stage IV (10 locations), parental clones and 1060 domestic and foreign clones in the CP historical nursery. The number of ratings for each genotype varied from a single rating in the unreplicated plots to more than 6 for the replicated trials. The highest rating is designated the assigned reaction.

Rust reactions based on whorl inoculation

Clones in the following CP Series were tested using the whorl inoculation technique: CP 05 Series in 2008 (Stage III increase) and 2009 (Stage IV), CP 06 Series in 2008 (Stage III) and 2009 (Stage III increases) and CP 07 Series in 2008 (Stage II) and 2009 (Stage III). Data are summarised to indicate the percentage of resistant clones at each stage. Correlations of the ratings in these different stages were made using clones common to each of the above series.

Results and discussion

Rust in commercial sugarcane production

The rust ratings of the commercial cultivars grown in Florida are presented (Table 1). Cultivar CP 80-1743 was the most susceptible and withdrawal from commercial production is recommended. Its acreage decreased from 22.8% in 2007 to 19.6% in 2009 prior to harvest and planting. In 2007, many growers could not change their planting plans because the orange rust resistance reaction of available, alternative cultivars could not be finalised prior to planting. Since 2007, the acreage of CP 88-1762 and CP 89-2143 increased by 1.9 and 4.2% to 20.4 and 31.1% respectively. Growers are reluctant to further increase CP 89-2143 and CP 88-1762 because these two cultivars are grown primarily on organic soils and the proportion of their acreage in some areas is very high (approaching 40%). Orange rust has recently been observed on CP 88-1762 that had not previously exhibited symptoms, suggesting a change in *P. kuehnii* pathogenicity. This is a real concern because shifts in pathogenicity can severely affect commercial production, cultivar deployment, and restrict the progress in the cultivar development program.

CP 78-1628 was resistant to *P. melanocephala* when it was released and for several years afterward, but now is moderately susceptible to brown rust. In Florida, brown rust has a history of affecting previously resistant cultivars. Brown rust resistance in CP 70-1133 and CP 72-1210 appeared to ‘breakdown’ as the acreage expanded above 30% in Florida. Similarly brown rust resistance of LCP 85-384 ‘broke down’ after its acreage approached 85%, contributing to its recent decline in Louisiana.
(K. Gravois, pers. comm.). In Colombia, brown rust severity has increased on CC 85-92 and CC 84-75 that combined occupy 80% of the acreage (Angel et al., 2008). The occurrence of new pathogenic races of either *P. melanocephala* or *P. kuehnii* are a real threat to the Florida industry since races of brown rust have been previously reported (Shine et al., 2005).

Orange rust development in 2009 has been slower than in 2008 since there was a severe freeze in March of this year and most of the sugarcane foliage was ‘burnt’ back by the freezing temperatures, thereby reducing the amount of *P. kuehnii* inoculum. The rust epidemic was delayed 3 months compared to the previous year, and orange rust severity in September was at a level comparable to that in July in 2008. Disease ratings based on natural infection were therefore delayed in 2009.

### Table 1—Rust reaction ratings based on natural infection and acreage of the major commercial cultivars grown in Florida in 2009.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Brown Rust (rating)</th>
<th>Orange Rust (rating)</th>
<th>% acreage</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP 72-2086</td>
<td>Mod. resistant (R1)</td>
<td>Susceptible (R3)</td>
<td>3.9</td>
</tr>
<tr>
<td>CP 78-1628</td>
<td>Susceptible (R2-3)</td>
<td>Mod. resistant (R1)</td>
<td>11.5</td>
</tr>
<tr>
<td>CP 80-1743</td>
<td>Mod. resistant (R1)</td>
<td>Susceptible (3)</td>
<td>19.6a</td>
</tr>
<tr>
<td>CP 84-1198</td>
<td>Mod. resistant (R1)</td>
<td>Mod. Resistant (R1)</td>
<td>3.7</td>
</tr>
<tr>
<td>CP 88-1762</td>
<td>Resistant (R0)</td>
<td>Mo. susceptible (R2)b</td>
<td>21.4</td>
</tr>
<tr>
<td>CP 89-2143</td>
<td>Resistant (R0)</td>
<td>Mod. susceptible (R2)c</td>
<td>32.6</td>
</tr>
</tbody>
</table>

a In June 2007 when orange rust was detected CP 80-1743 occupied 22.8% of the commercial acreage.

b CP 88-1762 previously had no orange symptoms but, in August 2009, orange rust was observed in multiple grower fields and it is now classified moderately susceptible.

c Orange rust severity has been rated R3 in some locations in 2009.

Recently released cultivars, CP 00-1101 (Gilbert et al., 2008), CP 00-1446 (Comstock et al., 2009), CP 00-2180 (Glaz et al., 2009), CP 01-1372 (Edme et al., 2009) and CPCL 97-2730 (Milligan et al., 2009) are either resistant or moderately resistant to rust (Table 2) and are rapidly being increased in Florida; however, the percent acreage of each cultivar in the industry still remains slightly below 1%. CP 80-1743 is not being replanted and the demand for these recently released resistant cultivars has been higher than the available seed cane for planting. The successful economic use of fungicides to control orange rust has enabled cropping for the normal crop cycle period, even in susceptible cultivars and has opened new control options to consider.

### Table 2—Rust resistance ratings of recently released cultivars.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Brown Rust (rating)</th>
<th>Orange Rust (rating)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP 00-1101</td>
<td>Resistant (R0)</td>
<td>Mod. resistant (R1)</td>
</tr>
<tr>
<td>CP 00-1446</td>
<td>Mod. resistant (R1)</td>
<td>Mod. resistant (R1)</td>
</tr>
<tr>
<td>CP 00-2180</td>
<td>Mod. resistant (R1)</td>
<td>Resistant (R0)</td>
</tr>
<tr>
<td>CP 01-1372</td>
<td>Mod. resistant (R1)</td>
<td>Mod. resistant (R1)</td>
</tr>
<tr>
<td>CPCL 97-2730</td>
<td>Resistant (R0)</td>
<td>Mod. resistant (R1)</td>
</tr>
<tr>
<td>CPCL 99-4455</td>
<td>Mod. resistant (R1)</td>
<td>Resistant (R0)</td>
</tr>
</tbody>
</table>

### Rust reaction of parental clones

A high proportion of parental clones available for crossing in 2007 and 2008 were susceptible to orange rust (Table 3). The short time period since the orange rust incursion has limited significant changes in the resistance of parental populations. The proportion of resistant parental germplasm was
less than Australia where 70% of the germplasm was resistant (Magarey and Bull, 2009). Consequently, changes in the breeding population have been more difficult in Florida than Australia. Although resistant × resistant and resistant × susceptible crosses are desirable, some crosses of susceptible × susceptible were made because of flower availability at the time of crossing. Some resistant progeny will be produced in these crosses. A more restrictive use of susceptible parental clones is being implemented.

Table 3—Summary of orange rust reactions of parental clones used for crossing in the CP program for Florida based on ratings taken in 2007 and 2008.

<table>
<thead>
<tr>
<th>Prefix</th>
<th>R0</th>
<th>R1 or R1+</th>
<th>R2 of R2+</th>
<th>R3 of R3+</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>CL</td>
<td>3</td>
<td>11</td>
<td>18</td>
<td>0</td>
<td>32</td>
</tr>
<tr>
<td>CPCL</td>
<td>5</td>
<td>15</td>
<td>32</td>
<td>4</td>
<td>56</td>
</tr>
<tr>
<td>CP</td>
<td>15</td>
<td>34</td>
<td>43</td>
<td>8</td>
<td>100</td>
</tr>
<tr>
<td>Total</td>
<td>23</td>
<td>60</td>
<td>93</td>
<td>12</td>
<td>188</td>
</tr>
</tbody>
</table>

*Prefix CL indicates clones developed entirely by the breeding program of US Sugar Corporation. CPCL prefix indicates clones derived from seed resulting from crosses made by the breeding program of US Sugar Corporation and selected by the CP program at the USDA-ARS Sugarcane Field Station. CP indicates clones developed entirely by the CP program.*

Of the 1060 clones in the CP historical nursery, 78 and 59% were classified as resistant to brown and orange rust, respectively. The nursery comprised primarily Florida (CP, CPCL, and CL), Louisiana (Ho, HoCP, L and LCP) and Texas (TCP) clones. Since the breeding and crossing programs for the US mainland sugar industries relies on these clones, the impact of orange rust is important.

**Effect of rust on the CP cultivar development program**

In 2007, the proportion of clones resistant \( R \leq 1.0 \) to both brown and orange rust that were advanced to Stage III (third clonal stage of selection) was 47.8% (Table 4). In 2008, 63.8% of the clones rated resistant \( R < 1 \) and advanced to Stage III (the first multi-location yield trial) were assigned a rating based on natural infection. Moreover, the mean rust rating of the entire population of Stage II clones decreased while the ratings of the check clones increased. The proportion of rust-resistant germplasm was less in Florida when orange rust was introduced than that in Australia in 2000, where 70% of the germplasm was resistant (Magarey and Bull, 2009). Guatemala also has a lower proportion of resistant germplasm in their selection program than Australia (W. Ovalle, pers. comm.). The lower proportion of resistant clones in the western hemisphere than Australia may be because, in Australia, \( P. kuehnii \) had been present for years and there probably was some selection for resistance in contrast to western hemisphere where the pathogen was newly introduced.

Table 4—Rust ratings of Stage II clones advanced to Stage III, 2007 versus 2008.

<table>
<thead>
<tr>
<th>Rust rating</th>
<th>2007</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>32 (23.5%)</td>
<td>86 (63.8%)</td>
</tr>
<tr>
<td>0.5–0.9</td>
<td>33 (24.3%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>1.1–1.4</td>
<td>48 (35.3%)</td>
<td>40 (29.6%)</td>
</tr>
<tr>
<td>1.5–1.9</td>
<td>21 (15.4%)</td>
<td>9 (6.7%)</td>
</tr>
<tr>
<td>2</td>
<td>2 (1.5%)</td>
<td>0</td>
</tr>
<tr>
<td>Mean</td>
<td>0.8</td>
<td>0.4</td>
</tr>
<tr>
<td>Check mean</td>
<td>0.8</td>
<td>1.6</td>
</tr>
<tr>
<td>Population mean</td>
<td>1.6</td>
<td>1.1</td>
</tr>
</tbody>
</table>
There are two trends concerning sugarcane brown and orange rusts in the CP cultivar development program: 1. a trend toward more resistance. In time a shift toward resistance is likely to be more dramatic as selection for rust resistance will be emphasised compared to other traits, and 2. a possible change in orange rust pathogenicity.

Pathogenic changes are evident since CP 88-1762 did not have orange rust symptoms in 2007 when the disease was detected. Growers and scientists made numerous observations of crops of these major cultivars and, if orange rust was infesting them in 2007, it had to be at an extremely low level. In 2009, orange rust pustules were observed on CP 88-1762 for the first time. Only pathogenicity and molecular characterisation will confirm if in fact there are distinct races of *P. kuehnii* present in Florida.

**Whorl inoculation ratings**

The proportion of rust resistant clones in the CP 05, CP 06 and CP 07 series are presented in (Table 6); the proportion of resistant clones in the CP 05 through CP 07 clones was high. Since susceptible clones were not advanced, there was an increase in percentage of resistant clones in 2009 compared to 2008. There were good correlations between the ratings obtained in whorl-inoculated tests and those obtained using natural infection (Sood *et al*., 2009). The correlations were excellent between ratings obtained from one year to the next with $r^2$ values ranging from 0.75 to 0.83.

<table>
<thead>
<tr>
<th>Table 6 —The percent resistant CP 05, CP 06 and CP 07 Series clones as determined by the whorl inoculation procedure.</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Resistant clones</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>CP Series</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>CP 05 Series</td>
</tr>
<tr>
<td>91 100</td>
</tr>
<tr>
<td>CP 06 Series</td>
</tr>
<tr>
<td>86 98</td>
</tr>
<tr>
<td>CP 07 Series</td>
</tr>
<tr>
<td>78 97</td>
</tr>
</tbody>
</table>

*a* Comparison of rust reactions of CP 05 Series clones in Stage II increase and the clones advanced to Stage IV for 2008 and 2009, respectively.

*b* Comparison of rust reactions of CP 06 Series clones in Stage III and the clones advanced to Stage III increase for 2008 and 2009, respectively.

*c* Comparison of rust reactions of CP 07 Series clones in Stage II and the clones advanced to Stage III for 2008 and 2009, respectively.

**Conclusions**

Orange rust appeared suddenly and has dramatically affected the production of sugarcane in Florida and several Central American countries. The disease impacted both total sugarcane production and the retention of cultivars in the cultivar development programs. A major cultivar, CP 80-1743, is being withdrawn from commercial production and a number of potential Stage IV clones were eliminated solely for their rust reactions.

In commercial fields, fungicide applications increased sugar productivity from a range of 7.9 to 26% on CP 80-1743 in 2008, indicating partial losses due to orange rust (James Shine, Raul Perdomo and Michael Irey, pers. comm.) Where there was better control of orange rust with more frequent fungicide applications in experimental plots, the losses were higher (up to 40%) reflecting the maximum loss due to the disease (Richard Raid, pers. comm.). The parental population and the crossing strategy had to be changed to reflect the need for rust resistance. Changes in *P. kuehnii* pathogenicity mean that constant monitoring of the susceptibilities of cultivars in commercial
production and in sugarcane breeding programs is required. At this time, there is not sufficient molecular and varietal reaction data to determine the origin of *P. kuehnii* in the western hemisphere. Since orange rust is dispersed by windblown urediniospores, it may spread and potentially may impact most sugarcane producing areas in the western hemisphere.

REFERENCES


LES DIFFÉRENTES ROUILLES DE LA CANNE À SUCRE EN FLORIDE

Par

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MOTS-CLÉS: Rouille Brune de la Canne à Sucre, Rouille Orangée, Puccinia melanocephala, P. kuehnii.

Résumé

Les symptômes de la rouille orangée ont été observés pour la première fois en Floride en juin 2007 sur le cultivar CP 80-1743. L’agent causal, Puccinia kuehnii, a été subséquemment vérifié morphologiquement et moléculairement ce qui a constitué le premier rapport de la rouille orangée dans l’hémisphère ouest. La maladie était prévalente à travers l’industrie de la canne à sucre en Floride, principalement sur les cultivars CP 80-1743 et CP 72-2086. L’objectif de cette recherche a été d’évaluer la réaction des cultivars industriels à la rouille brune et à la rouille orangée afin de déterminer leur impact sur le programme de développement des cultivars CP en Floride. Les réactions aux différentes rouilles de plusieurs cultivars plantés sur une grande échelle, les cultivars nouvellement homologués, les clones en sélection, les clones parentaux et les clones CP historiques ont été évalués afin de développer une stratégie de lutte basée sur la résistance pour contrecarrer l’arrivée de la rouille orangée. Les changements au programme pour augmenter le niveau de résistance à la rouille sont élaborés.
ROYAS DE LA CAÑA DE AZÚCAR EN LA FLORIDA

Por

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PALABRAS CLAVE: Roya Café, Roya Naranja, Puccinia melanocephala, P. kuehnii.

Resumen

Los síntomas de roya de la caña de azúcar de naranja se observaron por primera vez en la Florida en Junio de 2007, sobre el cultivar CP 80-1743. El agente causal, Puccinia kuehnii, fue verificado morfológica y molecularmente lo que se constituyó en el primer informe sobre presencia de la roya naranja de la caña de azúcar en el Hemisferio Occidental. La roya naranja está distribuida en toda la industria azucarera de la Florida, principalmente en las variedades CP 80-1743 y CP 72-2086. El objetivo de esta investigación fue evaluar la reacción de los cultivares comerciales tanto a la roya café como a la naranja de caña de azúcar y evaluar su efecto en el programa de desarrollo de cultivares CP en la Florida. Las reacciones de infección de varios cultivares comerciales ampliamente cultivados, de cultivares recién liberados y clones del programa de selección así como clones progenitores y clones históricos CP se evaluaron con el fin de desarrollar una estrategia de resistencia adecuada para hacer frente a la amenaza de la roya naranja en la industria azucarera de la Florida. Los cambios en el programa de mejoramiento para aumentar el nivel de resistencia en la progenie se presentan en detalle.
MONITORING THE SEVERITY AND VARIABILITY OF BROWN RUST (*Puccinia melanocephala*) IN SUGARCANE VARIETIES IN THE CAUCA VALLEY, COLOMBIA

By

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KEYWORDS: Sugarcane, Brown Rust, Disease Incidence, Ribosomal DNA (Rdna), Resistance, Physiological Races.

Abstract

The varieties CC 85-92 and CC 84-75 are grown on more than 80% of the area planted with cane in the Colombian sugar industry; these varieties were initially resistant to brown rust disease. Brown rust has been present in Colombia since 1979. Genetic variability in *Puccinia melanocephala* is thought to have affected resistance in some varieties through the appearance of what are thought to be new races of the pathogen. This situation has been observed in some resistant varieties (e.g. CC 85-92, CC 84-75, CC 93-3895), where recently the disease has occurred at low severity. Therefore, an evaluation was made of the severity and possible variability of brown rust in the varieties selected by CENICAÑA in the Cauca River Valley. Samples were taken from plants from 1–14 months of age in the varieties CC 84-75, CC 85-92, CC 93-3895, CC 92-2804 and MZC 74-275 on 91 estates (10 sugar mills). On each plantation 20 stalks were selected at random, and the third leaf from the top visible dewlap leaf was taken from each stalk. Both disease reaction and severity were evaluated. Morphological and microscopic analyses of the structures found in the rust pustules were undertaken in leaf samples taken from each variety. Simultaneously, pathogen samples were collected and molecular techniques used (focusing on initiators of the ribosomal DNA (rDNA)) to detect possible genetic variation of *P. melanocephala*. The results showed that the disease reaction type in the varieties evaluated was 5 or less, with severities ranging from 0–12% leaf area affected. Variety MZC 74-275 showed susceptibility, with a reaction of 6 and a severity of 20% on the estates where it was evaluated. No differences were found among the morphological structures in the samples evaluated, all of which corresponded to *P. melanocephala*. The results obtained from the amplification of the ITS1 and ITS2 regions of the rDNA and from the PCR-RFLP did not show differences among the samples evaluated. These results could indicate that the variation of the pathogen is not reflected in its rDNA or that the molecular technique used was not sufficiently sensitive to detect small variations in the genome. Initial results about the presence or absence of gene Bru1 and susceptibility to brown rust are discussed.

Introduction

Brown rust of sugarcane caused by the fungus *Puccinia melanocephala* H. and P. Sydow was reported for the first time in the western hemisphere in 1978, spreading rapidly throughout the American continent.

In 1979, it was detected in the variety B 4362 in the provinces of Norte de Santander and Cesar in Colombia; two years later, it was found in the Cauca River Valley (Victoria *et al*., 1984; Victoria *et al*., 1988).

1
In Colombia, the disease occurs at greater severity in plants that are 4–5 months of age (Victoria et al., 1995); however, in older crops, the plant shows a certain degree of recovery, depending on varietal susceptibility (Victoria et al., 1995). In general, *P. melanocephala* delays plant development, which is manifested in a reduction in stalk length and the number of stalks per stool (Victoria et al., 1984) resulting in a decrease of up to 40% in crop production in some susceptible varieties (Raid and Comstock, 2006).

The best strategy for controlling diseases is cropping resistant varieties; therefore, a prime objective of the CENICAÑA varietal improvement program is to select rust-resistant varieties. To do this, the disease is assessed at 4.5 months crop age, using the scale of Purdy and Dean (1981), which determines the genotype-pathogen interaction (type of pustule: 0–9) and percent severity in the third leaf from the top visible dewlap leaf.

Depending on pustule type, varieties with a score over 5 are considered susceptible and 5 or less, resistant. Variety selection considers disease severity but seeks high stability of the varieties in their reaction to the disease, thereby achieving vertical and horizontal resistance simultaneously (Victoria et al., 1989). Nevertheless, according to Raid and Comstock (2006), rust resistance has not been stable in some cane varieties due to the genetic variability of the pathogen. Various authors have proposed the existence of pathogen races, based on changes in the susceptibility of varieties previously reported to be resistant (Liu, 1980; Dean and Purdy, 1984).

The existence of rust races, based on differential varietal reactions, has been found in India and Florida (Ryan and Egan, 1989; Shine et al., 2005). Evaluation of *P. melanocephala* races requires an effective methodology for identifying genetic variability among the possible different pathogen populations. Molecular markers like AFLP and ITS provide a useful tool for monitoring genetic changes in populations. In addition, analysis of rDNA sequences have been used to establish phylogenetic tree and genetic variations in fungi (Hibbet, 1992).

CENICAÑA’s varietal improvement program developed varieties in the series 84, 85, 92 and 93 and these have stood out in recent years for their agronomic and factory traits. These varieties are being multiplied and tested on a commercial scale by the sugar mills. Varieties CC 85-92 and CC 84-75 currently hold first and second place in area under cultivation respectively; but at this time there are other outstanding varieties such as CC 92-2804, CC 93-3895, which are still in the process of being multiplied.

In the past, these varieties had low rust infection; but, in the last three years, there has been a gradual increase in the incidence of the disease. It is possible that this response is due to an interaction between the pathogen and varietal resistance.

The purpose of this study was to evaluate the presence and severity of rust in varieties under different environmental conditions; to evaluate isolates of the fungus collected in commercial crops throughout the Cauca Valley; to use ITS and PCR-RFLP molecular markers to determine the possible existence of pathogen races; to assess the possible presence of resistance genes or whether the increased incidence of rust is due to environmental factors.

**Materials and methods**

**Evaluation of rust under different environmental conditions**

Brown rust incidence was assessed in plantations on 91 estates, in the following sugar mills: Castilla (4), Cabaña (4), Incauca (3), María Luisa (2), Mayagüez (3), Manuelita (22), Providencia (8), Risaralda (16), Riopaila (8), Sancarlos (18) and Sicarare (3) between 2006 and 2008.

The evaluation was conducted in crops ranging from 1–14 months of age in areas destined for both seed and commercial production. Varieties CC 85-92, CC 84-75, CC 93-3895, and CC 92-2804 were evaluated; the susceptible variety MZC 74-275 was used as the check.

In each plantation, a sample was taken from 20 randomly-selected sites within a crop. At all sites and in each variety, the third leaf from the top visible dewlap leaf on stalks was used to
evaluate pustule type or disease reaction (scale of 0–9) and the percent severity of the disease (0–100), based on the guidelines defined by Purdy and Dean (1981).

**Molecular evaluation**

**Samples**
Ten leaves of varieties CC 92-2804, CC 93-3895, CC 85-92, CC 84-75, MEX 52-29, MZC 74-275, CP 57-603, CC 98-68 and CC 94-5827 were collected in different commercial crops. The samples were placed in plastic bags and conserved in a Styrofoam (foamed polystyrene) cooler with ice until they reached the laboratory where the molecular evaluation was undertaken.

**Conservation of the pathogen and induction of sporulation**
Leaf pieces (approx. 20 cm long) were taken from diseased leaves with a Type 4 reaction (Purdy and Dean, 1981); that is, with chlorotic or red spots and unopened pustules. The leaf pieces were washed with distilled water, then by ethyl alcohol at 70% and again washed with distilled water. The fragments were placed in glass jars containing 50 mL benzimidazole solution (12.5 mg/L) (Asnaghi et al., 2001), each of which was placed within PVC cylinders with the openings covered with netting (tulle). They were then incubated under glasshouse conditions at 25°C, 60–85% RH for 1–2 weeks until sporulation.

**Extraction of the fungal DNA**
The methodology described by Virtudazo et al. (2001a) was used to enable DNA extraction from the spores contained in one pustule, so preventing the mixing of possible races in different pustules found on the same leaf.

**Amplification of DNA fragments**
ITS markers were used to amplify the ribosomal DNA (rDNA), a technique used in different phylogenetic and population fungal genetics studies (because there are multiple copies in the genome these are easy to amplify). Different pairs of initiators from both the rDNA and other regions of the genome were evaluated. The PCR products obtained after amplification were visualised in agarose gels al 1.5% (for fragments <1000 pb), run in TBE at 0.5 X and tinctured with ethidium bromide.

**Amplification of the ITS 1 and ITS 2 regions for the harvested population of P. melanocephala**
The regions with the best amplification were selected for evaluating the total population collected in the Colombian sugar zone. The ITS 1 region was selected for amplification (240 isolates in total), following the conditions described by Virtudazo et al. (2001a) with an annealing temperature of 56°C. The results were observed in agarose gels at 1.5%, tinctured with ethidium bromide.

**Enzymatic restriction of the resulting PCR products**
Different restriction enzymes (e.g. Hinf I, Xba I, Hae III, Alu I, Taq I, Mse I and Ava II) were used to find one that would digest the DNA and make it possible to visualise differences among the samples analysed. Fragments from the ITS 1 and ITS 2 regions (annealed PCR) were used. For the enzymatic restriction, 2.5 units of each tested enzyme were used with the associated buffer supplied by the commercial house, the latter at a final concentration of 1 X. The digestion temperature for the different enzymes was 37°C, except for Taq I, whose optimum temperature is 55°C. The digestion time for the different restriction reactions was 3 h 30 min., followed by a cycle of 80°C for 20 min. to denature the enzyme used. The results obtained with the different restriction enzymes were observed in agarose gels at 2.0%, run in TBE 0.5 X and tinctured with ethidium bromide.

**Results and discussion**
The measurement of pathogen paraphyses and urediniospores contained in rust pustules on leaves of the varieties CC 85-92 and CC 93-3895 confirmed that the infection was caused by P.
melanocephala, causal agent of brown rust (Virtudazo et al., 2001b). Abundant paraphyses were observed, all the urediniospores were ovoid in shape, and brown-coloured teliospores were observed. In general, all the traits observed coincided with the descriptions of *P. melanocephala* and not *P. kuehnii* (Virtudazo et al., 2001b).

**Evaluation of the rust under different environmental conditions**

Variety CC 85-92, evaluated on 23 estates in 9 sugar mills, had one Type 5 disease reaction with a rust severity less than 8% in plants 4–6 months of age. At younger ages (4 months), the greatest severity was 8% with a Type 5 reaction in plants on the Palosecal 5 estates of Incauca. At older ages, the severity ranged from 0–4%, with types 0–5 reaction.

Variety CC 84-75 was evaluated on 9 estates of the Providencia, Riopaila and Castilla sugar mills. The highest disease severity was 10% with a Type 5 reaction at crop ages of 4.6 and 5.0 months on the Venecia 340 and La Luisa 80 estates of the Riopaila Sugar Mill. At crop age less than 4 months, disease severity ranged from 0–8% with reactions from 0–3. At older ages, disease severity and reaction were both zero (Table 1).

**Table 1**—Incidence of brown rust in variety CC 84-75 on different estates and sugar mills in the Cauca Valley.

<table>
<thead>
<tr>
<th>Sugar mill/estate</th>
<th>Age (Mo)</th>
<th>Rust*</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROVIDENCIA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>El Edén</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Zabaletas Racines 7</td>
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<tr>
<td>RIOPAILA</td>
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<td></td>
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<tr>
<td>Valparaiso</td>
<td>3.5</td>
<td>0</td>
</tr>
<tr>
<td>Venecia</td>
<td>4.6</td>
<td>5</td>
</tr>
<tr>
<td>La Luisa 080</td>
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<td>5</td>
</tr>
<tr>
<td>Riopaila 590</td>
<td>6</td>
<td>4</td>
</tr>
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<td>Riopaila 092</td>
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<td>0</td>
</tr>
<tr>
<td>CASTILLA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>La Porfina 050</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Potrerillo 050</td>
<td>4</td>
<td>4</td>
</tr>
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</table>

* R: Reaction (Scale 0–9); S: Severity (0–100%)

Variety CC 93-3895 was evaluated on 39 estates in 7 sugar mills. The greatest severity (15%) was found on the Esmeralda Estate of the Sancarlos Sugar Mill with a Type 5 pustule score at 4 months of age. At younger crop ages, disease severity ranged from 0–12% with reactions from 0–5. From 6–8 months, the score remained at 5, with severities ranging from 10–12%. At older ages (9 months), the severity was lower (Table 2). Variety CC 92-2804 was evaluated on three estates in the Sancarlos, Providencia and Risaralda sugar mills. Disease severity in these lots did not exceed 2%, with types 4 and 5 reactions. The check MZC 74-275 continued to show its susceptibility on all three estates with disease severities of 20% and a Type 6 reaction (Table 3).

It should be noted that every year CENICAÑA selects new varieties resistant to smut, brown rust and mosaic. This does not mean that these varieties are immune, given that immunity can easily cause the generation of pathogenic variations (new races) of the causal agents. In the case of brown rust, varieties with disease reactions from 0–5 are considered resistant, with severities less than or equal to 15% leaf area affected.

A reaction score of up to 5 is acceptable because climate (temperature, rainfall and RH) has little effect on disease severity with varieties of this rating; however, at higher scores, severity is highly affected by the climatic conditions (Victoria et al., 1989).
### Table 2—Incidence of brown rust in variety CC 93-3895 on different estates and sugar mills in the Cauca Valley.

<table>
<thead>
<tr>
<th>Sugar mill/estate</th>
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<th>Severity S</th>
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<tr>
<td>Palmera Guzmán 60B</td>
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<tr>
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<td>7.4</td>
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<td>12</td>
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<td>7</td>
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<tr>
<td>Olga 145 A</td>
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<td>Esmeralda 86</td>
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</tr>
</tbody>
</table>

*R: Reaction (Scale 0–9); S: Severity (0–100%)

Brown rust severity evaluation in varieties CC 85-92, CC 84-75, CC 93-3895 and CC 92-2804 showed that the reactions reached a maximum of 5 with a severity under 12%, which means that these varieties remain at rust-resistant levels (Victoria et al., 1989).

Varietal selection and regional trial records suggest that disease severity has remained in the stated ranges.
Table 3—Incidence of brown rust on variety CC 92-2804 and MZC 74-275 on different estates and sugar mills in the Cauca Valley.

<table>
<thead>
<tr>
<th>Variety/sugar mill/estate</th>
<th>Age (Mo)</th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>R</td>
</tr>
<tr>
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<td></td>
</tr>
<tr>
<td>SANCARLOS</td>
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<td></td>
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</tr>
<tr>
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</tr>
<tr>
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<td></td>
</tr>
<tr>
<td>Estampilla 2</td>
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<tr>
<td>MZC 74-275</td>
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<td></td>
</tr>
<tr>
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<td></td>
</tr>
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<td>Argelia 212A</td>
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<tr>
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</tr>
<tr>
<td>Galia sopinga 32</td>
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<td>5</td>
</tr>
</tbody>
</table>

* R: Reaction (Scale 0–9); S: Incidence (0–100%)

Molecular evaluation

Genetic variability was assessed in the different rust samples collected on the affected plantations, using different ITS ribosomal markers and the PCR-RFLP methodology.

The results obtained did not show differences in the molecular size of the bands among the samples evaluated (Figure 1).

All the samples evaluated with the ITS initiators showed one intense band of approximately 670 pb, thereby making it impossible to obtain differences demonstrating pathogen variability. The PCR-RFLP technique increased the number of bands in each analysis, but did not show differences among the samples evaluated.

Figure 2 shows the results obtained after digestion of the ITS 1 region with restriction enzyme Alu I. The results obtained with the other enzymes were similar with no polymorphism among the samples.

![Fig. 1—PCR products (670 bp) of the amplification of the ITS 1 region of P. melanosephala in different isolates collected in the Colombian sugar zone. The result for 240 samples evaluated was similar to that recorded for these 19 samples. MP: Molecular weight marker, 50 pb.](image-url)
In addition to the ITS 1 region of the rDNA, other DNA regions of the pathogen were evaluated; however, again there was no polymorphism with the different initiators, in agreement with results obtained with the ITS 1 region analysis. Similarly, the results obtained using the amplified ITS 2 region after digestion with restriction enzymes did not show differences among the samples evaluated, as can be seen in Figure 3.

Molecular tools failed to link pathogen genetic variability with variation in disease severity in varieties. However, this situation does not mean that there are no allelic differences among different pathogen samples.

This could be the result of the low resolution of the techniques used, which are only capable of detecting macro modifications at the pathogen DNA level. Limiting the study to the ribosomal region of the DNA limits the scope of the evaluation, given that many of the changes at the genomic level of the populations are not necessarily reflected at the rDNA level, especially if these changes imply an increase in the performance of a group of individuals due to specific changes in genes related to pathogen virulence.

The exclusive utilisation of rDNA in this study was primarily due to the impossibility of obtaining large quantities of DNA from the limited fungal tissue available and the impossibility of *in vitro* cultivation given that it is a biotrophic organism, incapable of growing in axenic media (Braithwaite et al., 2009).

This situation limited the use of other molecular markers such as AFLP. This technique is capable of the rapid discrimination of samples due to the great polymorphism that it generates, but this also requires larger quantities of DNA (200–500 ng); this is not possible to obtain from just one rust pustule.
The potential limitation of the molecular techniques for detecting gene variation is reflected by the ability to separate genetically 1305 varieties of CENICAÑA’s germplasm using five microsatellites, but it was not possible to separate somatic variations (highly susceptible to rust) found in normally resistant variety CC 01-86 (Macea et al., 2009). The microsatellite analysis showed that both genotypes were similar. Recently, Garsmeur et al. (2009) reported the presence of a major gene (Bru1) associated with brown rust resistance in the variety R 570 and common to most rust-resistant varieties. According to these authors, only 13% of the resistant varieties lack the Bru1 gene, suggesting that their resistance is due to the presence of another resistance gene. The Bru1 gene found in the original CC 01-86 was not found in the somatic variations. Nevertheless, in CENICAÑA, brown rust has been observed with equal severity in varieties that do have the Bru1 gene (21.6% of the affected varieties have the gene) and those that lack it. In addition, the disease has also been absent in varieties that lack the Bru1 gene (34% of the resistant varieties) (Gutiérrez, A.F., unpublished information).

Conclusions

Brown rust was found affecting some resistant varieties developed by CENICAÑA. Rust resistance has been consistent in the varieties CC 85-92, CC 84-75, CC 93-3895 and CC 92-2804.

The results obtained in this study did not show genetic variability among different samples of brown rust collected from Colombian sugarcane crops.

Studies that use other more informative molecular markers, such as AFLP and cDNA-AFLP, or that include sequencing of the fragments similar to that obtained with PCR may be required to detect nucleotide changes among the evaluated samples. This will help confirm the existence or not of genetic diversity in the rust isolates.

REFERENCES


SURVEILLANCE CONTINUE DE LA SÉVÉRITÉ ET LA VARIABILITÉ DE LA ROUILLE BRUNE (PUCCINIA MELANOCEPHALA) DANS LES VARIÉTÉS DE CANNE À SUCRE DANS LA VALLÉE DE CAUCA EN COLOMBIE

Par

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jcancel@cenicana.org

MOTS CLÉS: Canne à sucre, Rouille Brune, Incidence de Maladie, Résistance, ADN Ribosomique (rDNA), Races Physiologiques.

Résumé
Les variétés CC 85-92 et CC 84-75, initialement résistantes à la rouille brune, sont cultivées sur plus de 80% de la superficie sous canne à sucre en Colombie. La maladie est présente en Colombie depuis 1979. La variabilité génétique du *Puccinia melanocephala* est estimée avoir affecté la résistance de certaines variétés par l’apparition de nouvelles races du pathogène. Cette situation a été observée dans quelques variétés résistantes (e.g. CC 85-92, CC 84-75, CC 93-3895) où la maladie était apparue à faible intensité. En conséquence, une évaluation de la sévérité et de la variabilité de la rouille brune a été effectuée dans les variétés sélectionnées par le CENICAÑA dans la vallée de la Rivière Cauca. Les échantillons ont été collectés des variétés CC 84-75, CC 85-92, CC 93-3895, CC 92-2804 et MZC 74-275, âgées de 1–14 mois, sur 91 établissements (10 sucreries). Pour chaque plantation, 20 tiges ont été choisies au hasard, et la troisième feuille de TVD collectée de chaque tige. La réaction et la sévérité face à la maladie étaient évaluées. Des analyses morphologiques et microscopiques de la structure des pustules de rouille étaient entreprises sur les échantillons de feuille pour chaque variété. Simultanément, des échantillons du pathogène ont été collectés et analysés par les techniques de biologie moléculaire (en se focalisant sur les initiateurs d’ADN ribosomique (rDNA)) pour détecter une éventuelle variabilité génétique du *P. melanocephala*. La réaction des variétés testées atteignait au maximum le niveau 5 sur l’échelle d’évaluation, avec des sévérités s’étendant de 0-12% de la surface de la feuille. La variété MZC 74-275 a montré une sensibilité de niveau 6 et une sévérité de 20% sur tous les établissements où elle a été évaluée. Aucune différence n’a été observée parmi les structures morphologiques dans les échantillons, toutes correspondaient au *P. melanocephala*. Les résultats obtenus de l’amplification des régions ITS1 et ITS2 de la rDNA et de la PCR-RFLP n’ont pas montré de différence parmi les échantillons examinés. Ces résultats démontreraient que la variabilité du pathogène ne se situait pas au niveau de son rDNA ou bien que les techniques moléculaires utilisées n’étaient pas suffisamment sensibles pour détecter des variabilités minimes dans le génome. Les résultats initiaux sur la présence ou l’absence du gène *Bru1* et la sensibilité à la rouille brune sont discutés.
SEGUIMIENTO Y VARIABILIDAD DE LA ROYA CAFÉ (*Puccinia melanocephala*) EN
VARIEDADES DE CAÑA DE AZÚCAR EN EL VALLE DEL CAUCA

Por

JUAN C. ÁNGEL, ANDRÉS F. GUTIÉRREZ, JERSHON LÓPEZ, MARÍA L. GUZMÁN,
LINA M. CARDONA y JORGE I. VICTORIA

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PALABRAS CLAVES: Roya Café, Incidencia,
ADN ribosomial (ADNr), Resistencia, Variación.

Resumen

Las variedades CC 85-92 y CC 84-75 ocupan más de los 80% del área sembrada con caña en el sector azucarero colombiano, variedades inicialmente resistentes a la roya cafí. Esta enfermedad se encuentra presente en Colombia desde 1979. La posible variación genética de *P. melanocephala* ha afectado la resistencia en algunas variedades probablemente debido a la aparición de nuevas razas del patógeno. Esta situación se ha observado en algunas variedades resistentes (CC 85-92, CC 84-75, CC 93-3895, etc.) y en donde recientemente se ha observado la enfermedad con baja severidad. Por lo cual se procedió a evaluar la severidad y variabilidad de la roya cafí en las variedades seleccionadas por Cenicana en el valle del río Cauca. Se realizaron visitas a 91 haciendas de 10 ingenios sembrados con las variedades CC 84-75, CC 85-92, CC 93-3895, CC 92-2804 y MZC 74-275. En cada plantación se tomó al azar la tercera hoja a partir de la hoja TVD de 20 tallos y se evaluó la reacción y severidad de la enfermedad. Un análisis morfológico y microscópico de las estructuras encontradas en las pústulas de las diferentes variedades se realizó en las muestras recolectadas. Simultáneamente se realizó la recolección de diferentes muestras del hongo y mediante el uso de técnicas moleculares (ADN ribosomal (ADNr)), se determinaron las relaciones filogenéticas y variaciones genéticas en el hongo. Se evaluaron plantaciones desde los 1 a 14 meses de edad. Los resultados mostraron que en las variedades evaluadas el tipo de pústula fue de 5 o menos con severidades entre 0 y 12%. En las haciendas evaluadas con MZC 74-275, la variedad presentó susceptibilidad con reacción 6 y severidad del 20%. No se encontraron diferencias entre las estructuras morfológicas en las muestras evaluadas y correspondieron a *P. melanocephala*. Los resultados de la amplificación de las regiones ITS1 e ITS2 del ADNr no mostraron diferencias entre las muestras evaluadas. Por esto se procedió a realizar digestión de los productos de PCR con enzimas de restricción, sin embargo tampoco se observaron diferencias entre las muestras. Estos resultados podrían indicar que la variación del patógeno no se refleja en su ADNr o que la técnica molecular utilizada no es lo suficientemente sensible para detectar pequeñas variaciones en el genoma. Resultados iniciales sobre la presencia o ausencia del gen Bru1 y la susceptibilidad a la roya son discutidos.
ROOT AND BASAL STEM ROT DISEASE OF SUGARCANE IN LAMPUNG, INDONESIA

By

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KEYWORDS: Xylaria sp., Stroma, Yield Loss.

Abstract

The root and basal stem rot disease is new to Indonesia. It was detected in 1993 on a commercial variety grown in Gunung Madu sugarcane plantation, Lampung. Infected plants have been more frequently found thereafter on newer varieties and the disease is becoming more important to the plantation. Based on field observations, the infection in contaminated fields may reach 11% stalk infection. Symptoms appear on mature plant crops (9 month and older), and on younger plants in ratoon crops (5 month and older), as yellowing or drying of cane leaves. Under very severe infection, the symptoms could be visible much earlier and may be followed by patches of dying stools across the field. Because of the rotten roots and basal stem, the infected plant is easily pulled out of the ground. The key indicator of the infection is the emergence of multiple branched stroma that protrude from the ground around the cane stool, and from the dead stubbles. In general, the disease characteristics are very similar to the root and basal stem rot disease reported from Taiwan. The CABI Identification Services, England, upon examinations on the anamorphic and teleomorphic states of the causal pathogen, has almost certainly confirmed that the causal pathogen in Indonesia and Taiwan is similar, namely Xylaria cf. warburgii. Yield loss assessment conducted on artificially inoculated plant crops in the field revealed that at 25–26% infection severity the particular disease could potentially reduce the cane and sugar yield by 12.3% and 15.4%, respectively.

Introduction

The root and basal stem rot, a relatively new and rare disease of sugarcane, was first reported from Taiwan. Fang et al. (1986) reported that the disease was caused by Xylaria cf. warburgii. A disease with similar characteristics was detected in 1993 in Indonesia, on a commercial variety grown in PT Gunung Madu Plantations (GMP), a sugar plantation in Lampung province (approximately 4°42'S/105°12’E).

The characteristics of the disease are similar to that reported from Taiwan. Quite often disease occurrence is recognised very late, where patches of drying and dying stools across the field have become very pronounced.

Infected plants have been more frequently found on newer varieties thereafter, and the disease is becoming more important in GMP. Based on field observations in 2002–2007, the infection in contaminated fields may reach 11% stalk infection (unpublished data). Fang et al. (1994) in Taiwan estimated that X. warburgii caused a yield loss of 5% in plant crops and 30% or higher in ratoons.

Despite the similarity, it was not clear whether the causal pathogen is the same as in Taiwan. The present paper reports the findings of studies related to the disease in GMP. The studies have been conducted since 2002, aiming to characterise disease infection in the field; to understand fungus morphology for necessary identification and pathogen confirmation; and to assess yield loss.
caused by the disease. The outputs are expected to complement current knowledge on this rare disease of sugarcane.

**Material and methods**

**Characterisation of disease infection in the field**

This is to characterise typical appearance of disease infection in the field, to help plantation staff to be alerted to any symptoms of disease. Spots with premature yellowing or drying leaves in mature plant crops were inspected. The stalks were pulled out and split longitudinally. Typical appearance of both above- and underground parts was then characterised upon confirmation of disease infection. Similar approaches but on younger canes were done in ratoons.

**Morphological description**

Materials from infected plants, including protruding stromata associated with the infection in the fields, were collected and brought to the laboratory for detailed morphological examination under the microscope. The morphological description was used for pathogen identification.

**Confirmation of pathogen**

The basal stems of the infected plants were thoroughly cleaned, split up, and chopped to take a small piece (ca. 1 cm³) of stem tissues covering the transitional zone of the advancing pathogen and healthy tissue in front of it. This material was rinsed and dipped in an alcohol solution for 5 min. and the rind was removed aseptically. The inner portion was finely sliced and transferred to a PDA medium containing terramycin 0.02%. The developing culture was purified and the pure isolates were further propagated on the same media to be used on second step propagation on coarse media.

Mango twigs media were used for second propagation, following Fang et al. (1986) and Fang et al. (1994). In the present study, the same isolates were also propagated on fine slices of sugarcane tissues. The mango twigs and sugarcane slices were dipped separately in water for 2 hrs and transferred into 500 mL flasks. About 300 g of each medium was put in a flask. The flasks and these coarse media were autoclaved for 1 h (121°C, 15 psi), and this step was repeated one more time the next day. One tube of pure isolates as already prepared (of 1 month age) was used to inoculate each flask of coarse medium, followed by incubation for 2 months under 26–28°C. The colonies produced were used to inoculate the plants in subsequent pot/poly-bag experiment.

The use of colonies on coarse media, rather than on standard agar media, was preferred for an inoculation under soil environment in a pot experiment. A previous experiment suggested that standard inoculum failed to enhance infection of fungus on target plants under such environment, likely because the inoculated fungus could not persist for a longer time due to limited nutrient reserves in the standard agar medium.

The fungi colony would find the mango twigs and sugarcane slices as better nutrient resources in the soil before any infection on target tissues could take place.

Sugarcane and maize were used as test-plants. They were grown on poly-bags filled with 10 kg pre-sterilised soils. Maize was selected for having a shorter life cycle which should facilitate the trial, while it was also reported as susceptible and responsive to root and basal stem rot disease infection in Taiwan (Fang et al. 1994).

Each poly-bag with two plants of either sugarcane or maize was inoculated by burying (5–10 cm deep) the previously prepared colonies (inoculated mango twigs and sugarcane tissues). Sterilised, non-inoculated mango twigs and sugarcane materials were buried instead in control treatments. Each treatment was replicated 5 times. Regular watering was done to maintain plant growth but no fertiliser was applied.

Any wilting, yellowing, or drying plant was pulled out of the poly-bag. The basal stem was split and observed for any disease symptom. The diseased tissues were again isolated to confirm the causal pathogen.
Yield loss assessment

A field experiment was carried out in plant cane in 2002–2003. Plot size was 9 rows x 10 m. Two local varieties (GM19 and PSGM88-5052) with three inoculum dosages (0/control, 250 g, and 500 g for each metre of row) were used. A complete randomised block design with 3 replications was applied.

Inoculum was prepared by shredding the roots and basal stems of diseased plants. The materials were air dried for 2–3 weeks under ambient temperature. At planting, these inoculum materials were broadcast on the bottom of planting furrows, and then the cane setts were manually planted and covered.

The observations were done at harvest age. Three rows in each plot were dug out and the number of millable stalks per metre was counted. The length of discoloration (representing infection symptom) and stalk diameter were measured, then the ratio of length of symptom to stalk diameter was calculated. The ratio figures were specifically used in the assessment of severity of infection, to eliminate any bias on disease impacts that may have resulted from variable stalk diameter within the stalk population. Disease infection severity was then calculated by the following formula,

\[ I = \sum \frac{(n \cdot v)}{N \cdot V} \times 100\% \]

where

- \( I \) = disease infection severity
- \( n \) = number of stalks having a common value of disease symptom (in 3 sample rows)
- \( v \) = value of symptom (0, 1, 2, 3, or 4), see Table 1 for classification
- \( N \) = total number of stalks (in 3 sample rows)
- \( V \) = highest value of symptom (=4)

Table 1—Classification of symptom value.

<table>
<thead>
<tr>
<th>Symptom length : stalk diameter (x)</th>
<th>Symptom value (v)</th>
</tr>
</thead>
<tbody>
<tr>
<td>x = 0 (no symptom)</td>
<td>0</td>
</tr>
<tr>
<td>0 &lt; x &lt; 1</td>
<td>1</td>
</tr>
<tr>
<td>1 &lt; x &lt; 2</td>
<td>2</td>
</tr>
<tr>
<td>2 &lt; x &lt; 3</td>
<td>3</td>
</tr>
<tr>
<td>x &gt; 3</td>
<td>4</td>
</tr>
</tbody>
</table>

Ten sample stalks from each plot were weighed and subsequently crushed by using a laboratory mill for juice pol analysis. Differences of stalk weight and pol % juice between controls (without artificial inoculation) and treated plots (with artificial inoculation) would represent yield and sucrose losses.

Results and discussion

Characterisation of disease infection in the fields

In general, the characteristics of disease infection were similar to those described in Taiwan. In plant crops, disease infection is visible on mature plants of 9 months or older. When the rotten section at the basal stem becomes so extensive and reaches ground level, the leaves would start yellowing and drying. At this condition, the plants are easily pulled out of the ground because the roots and the basal stem have already rotted and dried. Upon splitting, the infected tissues looked pale and many lateral lines or spots, dirty white in colour, are clearly visible, representing fungal mycelia.

In ratoon crops, the drying leaves could be found on younger canes, namely on 5–7 month old plants. The symptoms here appear earlier because the infection is actually a continuation of
previous infection (in plant crops), developing from old stubbles to the newly growing tillers (secondary infection). There will be patches of depleted tiller population under very severe infection. These patches are visible as early as on 1.5 to 4 month old canes. The size of the patches varies from very small to 100 m² or even wider, wherein invasion of weeds would easily take place.

The key indicator of the infection of root and basal stem rot disease in the field is the occurrence of white tipped black stromata protruding from the dead stubbles or from underground parts around the sugarcane stool. Upon splitting, the diseased tissues smell like rotten wood. A strong sour smell is never associated with this disease.

Under closer observation, there are actually two types of stroma found in the fields. The first one has multiple branches with abundant white conidia easily visible on their tips, which is easily found in the contaminated fields.

The second one has a sausage-like fruiting body, a single structure with no branches. Both stroma have black external appearance but they are white inside. A detailed morphological description was obtained after microscopic examination.

**Morphological description and pathogen identification**

The multiple-branched stroma is the anamorphic state and may be considered as sterile stroma (Fang et al., 1994). Conidia isolates from GMP consisted of single cells, hyaline, and have an oval form. The conidia size here is bigger compared to those reported from Taiwan. On average they are 5.0–13.0 µm long by 2.5–8.0 µm wide, compared to 4.0–8.0 µm by 1.8–2.1 µm of the Taiwanese (Fang et al., 1994).

The second type with sausage-like fruiting body is the teleomorphic state. It is clear under the microscope that the rough surface of the fruiting body actually consists of perithecia, and reported as perithecial-stroma by Fang et al. (1994). The size of the ascospores is also slightly bigger compared to those found in Taiwan. They are 13.8–15.8 µm by 4.6–5.3 µm while, in Taiwan, they are 11–12 µm by 4–5 µm (Fang et al., 1994).

Based on the above morphological description, supported by available references particularly from Taiwan, it is suggested that the pathogen associated with root and basal stem root disease in GMP, Indonesia, is a *Xylaria* sp. Alexopoulos and Mims (1979) stated that the Xylariaceae family are mostly saprophytic or weakly parasitic of fungi on woody plants.

Their stromata are usually epixylous, stipitate, filiform to sausage-shaped, black outside but mostly white internally, and produce their perithecia over the entire fertile portion above the stipe.

Specimens for identification have been sent to CABI (Centre for Agriculture and Bioscience International) Identification Services, England. The Centre’s taxonomist at first had some difficulties in making identification when only the anamorphic state was available.

After the teleomorphic state was made available, he reported that the specimens were almost certainly the same species as the sugarcane pathogen referred to in Taiwan as *Xylaria* cf. *warburgii*. This species was originally described from New Caledonia from rotten fruit of *Sloanea* (Elaeocarpaceae), and is unlikely to be conspecific with the sugarcane fungus. ITS (internal transcribed spacer) sequence analysis confirmed that the fungus was a species of *Xylaria*, but there are no publically accessible ITS sequences of *X. cf. warburgii* (Cannon, 2009a, b).

**Confirmation of pathogen**

Fungus mycelia grew more profusely on mango twigs compared to on sugarcane slices. At the time of inoculation into the poly-bag, the mycelia have nearly covered the entire surface of the mango twigs while, on sugarcane slices, the mycelia did not grow on the sugarcane rind surface.

Disease infection was observed on the 75th day on maize plants, where initial symptoms have been visible at the basal stem and the leaves turned into straw colour. On sugarcane plants, the typical symptoms at ground level developed after 5.5 months. The extent of infection on the two test plants is presented in Table 2.
Table 2—Number of infected plants after inoculation.

<table>
<thead>
<tr>
<th>Inoculants</th>
<th>Infected plants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maize</td>
</tr>
<tr>
<td>Inoculated mango twigs</td>
<td>6 of 6</td>
</tr>
<tr>
<td>Inoculated cane stalk slices</td>
<td>4 of 11</td>
</tr>
<tr>
<td>Sterilised mango twigs</td>
<td>0 of 11</td>
</tr>
<tr>
<td>Sterilised cane stalk slices</td>
<td>0 of 12</td>
</tr>
</tbody>
</table>

It is shown that the infection took place only on plants inoculated with either mango twigs or sugarcane slices which were already colonised by the fungus, and there was no infection on plants ‘inoculated’ by sterilised materials. The infected maize and sugarcane plants in the poly-bags showed the same symptom as those on naturally infected plants in the fields. Because of restricted environment in the poly-bags, disease symptoms on sugarcane plants were developed earlier, on 5.5 month old plants, compared to 9 month old plants under natural environment in the fields.

The infected maize plants were chopped and some 20 pieces of infected tissues were then isolated in the laboratory. The culture produced the same fungus as originally inoculated. It confirmed that this particular fungus species, having such typical stromata which is easily found with or around the diseased plants in the fields, is the causal pathogen of the root and basal stem rot disease in GMP, Indonesia.

Cane seedpieces (setts) were used in this poly-bag experiment. Upon splitting the infected stalk, it could be suggested that the infection started from the sett roots or from root primordia encircling the nodes. Lines of mycelia were clearly visible on the nodes but not on the internodes. The infection was then expanded from the setts toward basal parts of the newly growing tillers.

Yield loss assessment

The two varieties used did not cause any significant effect on infection severity, stalk population, stalk weight, and pol % juice. There was also no significant effect on all parameters related to interaction of variety x inoculum dosage.

Table 3—Effect of inoculum dosage on plant crop.

<table>
<thead>
<tr>
<th>Dosage</th>
<th>Severity (%)</th>
<th>Stalk population (/ m row)</th>
<th>Stalk weight (kg)</th>
<th>Pol% juice</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 g/metre</td>
<td>0.3 a</td>
<td>11.6 a</td>
<td>1.38 a</td>
<td>18.43 a</td>
</tr>
<tr>
<td>250 g/metre</td>
<td>25.1 b</td>
<td>9.7 a</td>
<td>1.21 b</td>
<td>17.79 b</td>
</tr>
<tr>
<td>500 g/metre</td>
<td>26.2 b</td>
<td>9.5 a</td>
<td>1.21 b</td>
<td>17.78 b</td>
</tr>
<tr>
<td>LSD.05</td>
<td>5.34</td>
<td>2.35</td>
<td>0.10</td>
<td>0.60</td>
</tr>
</tbody>
</table>

Inoculum dosage, however, gave significant effect on infection severity, stalk weight, and pol % juice, but not on stalk population (Table 3). The infection on sugarcane plants through artificial inoculation under a field environment took place effectively. The infection severity was only 0.30% on the controls (without artificial inoculation), significantly lower than on 250 g and 500 g inoculum treatments (25.09% and 26.22% respectively). There was no significant difference between 250 g and 500 g inoculum treatments. (The smaller dosage should be sufficiently effective for use in any future studies involving field inoculation).

The ‘healthy’ plants (controls, without artificial inoculation) had significantly higher stalk weight compared to the diseased ones of the other two treatments, which suffered from 25.1% and 26.2% infection severity. Compared to the controls, the stalk weight of the other two treatments was 12.3% lower. Similarly, the pol % juice (representing sucrose content) on the diseased plants was...
significantly lower (around 3.5% in percentage) compared to the controls. Roughly, with infection severity of 25–26%, the root and basal stem rot disease could potentially reduce the cane and sugar yield on plant crops by 12.3% and 15.4%, respectively.

Conclusions

The root and basal stem rot disease found in GMP sugarcane plantation, Indonesia, is almost certainly caused by *Xylaria* cf. *warburgii*, similar to the causal pathogen of root and basal stem rot disease in Taiwan. However, the size of fungus conidia and ascospores here is somewhat larger compared to the Taiwanese.

The disease typically caused yellowing or drying of leaves on mature plant crops (9 month old) and on younger plants on ratoons (5 month old). Under very severe infection the symptoms could be visible much earlier and there will be patches of dying stools across the field. The most important indicator of disease infection in the field is the emergence of multiple branched stromata off the ground, around the cane stool, and from the dead stubbles.

At 25–26% infection severity on plant crops, the root and basal stem rot disease could potentially reduce cane and sugar yield by 12.3% and 15.4%, respectively.

REFERENCES


mortalité de souches à travers le champ. De par le fait que les racines sont pourries, la plante infectée est facilement arrachée. L’indicateur clé de l’infection consiste en une apparition de branches multiples de stroma sortant de terre autour de la base de la souche et des souches mortes. En général, les caractéristiques de la maladie sont similaires à la pourriture basale des racines et de la tige comme rapporté au Taiwan. Le CABI Identification Services, en Angleterre, après examen des stades anamorphique et téléomorphique, a presque confirmé que l’agent causal en Indonésie et au Taiwan est similaire, notamment le *Xylaria cf. warburgii*. Une évaluation de l’effet de la maladie sur le rendement a été effectuée en inoculant les plantes artificiellement au champ. Il a été démontré qu’une infection de 25–26%, pourrait occasionner une chute potentielle en rendement de canne et en sucre de 12.3% et 15.4%, respectivement.

**PUDRICIÓN BASAL DEL TALLO Y RAÍCES DE LA CAÑA DE AZÚCAR EN LAMPUNG, INDONESIA**

Por

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**PALABRAS CLAVE:** *Xylaria* sp., Estroma, Pérdidas en la Producción

**Resumen**

La pudrición basal del tallo y raíz es una enfermedad nueva para Indonesia. La afección se detectó en 1993 en una variedad comercial cultivada en Gunung Madu, Lampung. Desde entonces, se han encontrado plantas afectadas con mayor frecuencia en las nuevas variedades, convirtiéndose la enfermedad en importante para las plantaciones comerciales. Con base en las observaciones de campo, la infección en los campos afectados puede llegar a 11% de tallos enfermos. Los síntomas aparecen en las plantillas con plantas maduras (9 meses de edad o más), y en las socas, en plantas más jóvenes (5 meses o más), como un amarillamiento o secamiento de las hojas. En los casos de mayor severidad, los síntomas pueden ocurrir mucho antes, seguidos por la producción de parches de cepas muertas en el campo. Debido a la pudrición basal de los tallos y raíces, las plantas afectadas se pueden arrancar con facilidad. Un indicador clave de la infección es la aparición de estromas ramificados que aparecen en la tierra, alrededor de las cepas afectadas o brotes muertos. En general, las características de la enfermedad son muy similares a la pudrición basal del tallo y raíz registrada en Taiwán. Los servicios de identificación de CABI, Inglaterra, en los exámenes a los estados anamórfico y teleomórfico del patógeno causal, confirmaron que los agentes causales en Indonesia y Taiwán son similares, es decir, *Xylaria cf. warburgii*. La evaluación de pérdidas en la producción realizados en plantas inoculadas artificialmente en el campo mostraron que con una severidad entre el 25–26%, la enfermedad puede reducir la producción de caña y azúcar en 12.3% y 15.4%, respectivamente.
RESISTANCE SCREENING OF PROMISING SUGARCANE CLONES TO TWO RACES OF GUMMING DISEASE BACTERIUM

By

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KEYWORDS: Disease Resistance, Gumming Disease, Sugarcane, Xanthomonas Axonopodis Pv. Vasculorum.

Abstract
TWO RACES of the gumming disease bacterium (Xanthomonas axonopodis pv. vasculorum), Races 1 and 2, commonly infect sugarcane varieties in Mauritius. Clones selected from the 3rd clonal stage (years 4–5) of the breeding program are screened for resistance to these two races. From 1998 to 2007, 878 clones were tested in disease resistance trials in localities where the races are prevalent. Inoculated spreader rows of a susceptible variety act as the source of inoculum for the test varieties. Evaluation to Race 1 was carried out at one site; whereas, testing against Race 2 was conducted at two to four sites. Screening showed that 99% of clones were immune to Race 1. Of the 9 clones that showed infection, seven were classified as resistant, one slightly susceptible and one susceptible. In contrast, the percentage of clones showing immunity to Race 2 was much lower (14%). Resistance, slight susceptibility, susceptible, and high susceptibility to Race 2 were 44%, 23%, 13% and 6%, respectively, among the remainder of the clones. Ratings were consistent across locations for 78% of clones. Evaluation at more than one site was consequently justified. The pathogen was isolated from commercial fields in regions prone to the disease and in germplasm collections during the period 1998–2007. Race characterisation was based on cultural characteristics and pathogenicity tests. Race 1 was readily recovered in noble cane collections. Apart from one instance in 1998, it was absent in commercial fields. These surveys confirmed that commercial varieties were highly resistant to Race 1 and, therefore, of insignificant importance in Saccharum hybrids. Gumming disease prevalent in plantations was therefore almost exclusively caused by Race 2. This race was predominant and resistance screening against it in different environments is necessary.

Introduction
Gumming disease of sugarcane caused by Xanthomonas axonopodis pv. vasculorum is present in some 25 countries (Rott and Girard, 2000). The population of the pathogen is heterogeneous and five groups have been characterised on the basis of fatty acid analysis and genetic variability (Dookun et al., 2000; Saumtally, 1996). It is considered as the most important bacterial disease of sugarcane in Mauritius and three races, Races 1, 2 and 3 have been reported in order of their appearance (Ricaud and Autrey, 1989). Race 1 dates back to 1848, infects noble cane (Saccharum officinarum) and was presumably introduced when sugarcane was brought for cultivation on the island. Noble canes are no longer cultivated but this race can be readily found in germplasm collections. Race 2 appeared in 1964 and caused an epidemic on cultivar M 147/44. It is frequently encountered in parts of the island on susceptible varieties. Race 3 appeared in epidemic proportion in 1980 and particularly affected varieties M 442/51, M 31/45 and M 377/56. The latter two varieties were released as resistant to the disease. With the eradication of M 377/56, Race 3 has
been absent in sugarcane fields for a number of years. Control of gumming disease relies on preventive measures such as sanitation, disease-free planting material and, more importantly, the cultivation of resistant varieties. The latter has been very effective in minimising the spread of the disease and has led to its eradication in Australia and West Indies as well as reducing its impact in Brazil, the Caribbean Islands and Fiji (Ricaud and Autrey, 1989). In Mauritius, screening of clones is during years 4–5 of the 9–12 year selection program, when the number of varieties is reduced to less than 150. Variety evaluation is conducted at different sites, in relationship to the distribution of the races of the pathogen. Because of the absence of Race 3 during recent years, screening to this race has been discontinued. This paper analyses the results of variety evaluation to Races 1 and 2 from 1998 to 2007, and discusses the necessity of screening varieties to the disease in the light of the distribution of the races around the island.

Materials and methods

Resistance screening and disease ratings

Varieties selected from the 3rd clonal stage of the breeding program (years 4–5) were planted in July each year in resistance trials for evaluation of resistance to \( \textit{X} \alpha \textit{pv. vasculorum} \). Testing for resistance to Race 1 was conducted at one site (Réduit), while trials for resistance to Race 2 were established at two to four sites (Case Noyale, Ferney, Médine and Yemen). In all trials, highly susceptible varieties, acting as spreader rows, were inoculated in January with a bacterial suspension of either Race 1 or Race 2 at a concentration varying from \( 1 \times 10^8 \)–\( 10^9 \) cells/mL. Varieties under evaluation were planted on 3 m-row flanked by the artificially infected varieties. Test varieties along a row were also separated by a strip of inoculated varieties. Mixed \( \textit{S officinarum} \) clones acted as spreader rows for Race 1, while varieties M 147/44 and M 377/56 were used as inoculum lines for Race 2. The pathogen was naturally transmitted by leaf contact to the test varieties planted without replication.

Standards included in Race 1 trials were varieties M 147/44, M 31/45, M 377/56, M 3035/66 (all resistant), B 34104 and M 55/1182 (both highly susceptible). With the exception of M 31/45, also a resistant standard for Race 2, all resistant controls for Race 1 were included in Race 2 trials as susceptible checks, while M 442/51 was the slightly susceptible control for this race. Assessment was carried out 6 and 8 months after inoculation on a qualitative scale based on the severity of infection as follows: absence (immune), short stripes on old leaves (resistant), medium length stripes on old leaves (slightly susceptible), long stripes on old leaves with or without short stripes on young leaves (susceptible). Varieties are considered highly susceptible when they exhibited one or more of the following symptoms: heavy striping with several long stripes, leaf chlorosis, gum exudation and death of stalks. A second 3-point scale was also used to quantify abundance of foliar and systemic infection and further assess the degree of infection: I (low), II (intermediate) and III (high). For any given year, the same clones were evaluated at the different sites.

Collection of isolates and race characterisation

Isolates of \( \textit{X} \alpha \textit{pv. vasculorum} \) were collected from commercial sugarcane fields during island-wide surveys and from variety collections from April to October during 1998–2007. Inspections for gumming disease in susceptible varieties were made at locations known to be foci of infection. Sites surveyed were Belle Rive, Étoile, Ferney, Le Val, Quatre Soeurs (East), Case Noyale, Le Morne, Médine, Yemen (West), Quatre Bornes and Réduit (Centre). Varieties examined for symptoms were: \( \textit{S officinarum} \) clones, M 147/44, M 377/56, M 351/57, M 555/60, M 3035/66, M 1557/70, M 1286/89, M 2454/95, R 570 and R 579. The pathogen was isolated from sugarcane leaves or stalks. Infected leaf strips were surfaced disinfected with 70% ethanol for 1 min, washed in sterile distilled water (SDW) and directly streaked on sucrose peptone medium (composition per litre: peptone, 5.0 g; \( \text{KH}_2\text{PO}_4 \), 0.5 g; \( \text{MgSO}_4 \cdot 7\text{H}_2\text{O} \), 0.25 g; sucrose, 20 g; agar 15.0 g; pH 7.0). Diseased stalks were washed and the node thinly sliced after removing the rind. The sliced pieces
were allowed to diffuse in 5 mL SDW for 30 min before streaking the suspension on sucrose peptone medium. The incubation period was 3–5 days at 30°C.

Races were distinguished by their growth habit on TZC agar slants (composition per litre: peptone, 10 g; glucose, 5 g, casein hydrolysate, 1 g; tetrazolium chloride, 0.05 g; agar 15 g; pH 7.2) after 7–10 days incubation at 30°C. Race 1 is distinguished from Race 2 by the formation of a compact growth at the top of the tube owing to its viscous exopolysaccharide (EPS). In contrast, the EPS of Race 2 is more fluid and the colony flows down to the bottom of the slant. Confirmation of race identity was obtained by pathogenicity tests using noble cane varieties Iscambine Stripe, Senneville (*S. officinarum*) as well as hybrids M 147/44, M 31/45 and M 3035/66. Inoculated plants required monitoring for symptom development for up to two months. Race 1 infects the noble canes but none of the hybrids. Race 2 induces symptoms in all varieties, except M 31/45. Symptoms expression also differed between the two races. Race 1 only rarely causes slight leaf chlorosis. This symptom is common and intense in plants inoculated with Race 2.

**Results**

**Resistance screening and disease ratings**

Table 1 shows the annual and total number of clones tested from 1998 to 2007 across the various sites.

<table>
<thead>
<tr>
<th>Years</th>
<th>Réduit (Race 1)</th>
<th>Case Noyale (Race 2)</th>
<th>Ferney (Race 2)</th>
<th>Médine (Race 2)</th>
<th>Yemen (Race 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>1999</td>
<td>135</td>
<td>135</td>
<td>135</td>
<td>135</td>
<td>–</td>
</tr>
<tr>
<td>2000</td>
<td>143</td>
<td>–</td>
<td>143</td>
<td>143</td>
<td>143</td>
</tr>
<tr>
<td>2001</td>
<td>69</td>
<td>69</td>
<td>69</td>
<td>69</td>
<td>69</td>
</tr>
<tr>
<td>2002</td>
<td>79</td>
<td>79</td>
<td>79</td>
<td>–</td>
<td>79</td>
</tr>
<tr>
<td>2003</td>
<td>94</td>
<td>94</td>
<td>94</td>
<td>–</td>
<td>94</td>
</tr>
<tr>
<td>2004</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>–</td>
<td>90</td>
</tr>
<tr>
<td>2005</td>
<td>61</td>
<td>61</td>
<td>61</td>
<td>–</td>
<td>61</td>
</tr>
<tr>
<td>2006</td>
<td>65</td>
<td>65</td>
<td>65</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>TOTAL</td>
<td>878</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Inoculum pressure was adequate in the trials. For Race 1, the highly susceptible checks displayed the most severe symptoms of the disease. On the other hand, *Saccharum* hybrid controls were all immune to this race. For Race 2, the highly susceptible cultivars M 147/44, M 377/56 and M 3035/66 exhibited susceptibility to high susceptibility in all trials in conformance to their observed field reactions. The resistant variety M 31/45 displayed a resistant reaction to the two races, while M 442/51 was slightly susceptible to Race 2.

Screening to Race 1 revealed that most of the clones were immune. Of the 878 clones tested, 99% did not show any symptom to this race. Of the 9 clones that were infected, seven were resistant (M 1226/91, M 1954/91, M 1487/92, M 2773/94, M 2655/95, M 1641/97 and M 2181/00), one slightly susceptible (M 3096/94) and one susceptible (M 1866/90). When comparing the reactions of Race 1 resistant clones to that obtained with Race 2, all were more susceptible to the latter race, except clone M 1954/91 which was also resistant. Clone M 3096/94 was slightly susceptible to both races. However, inversely to the other clones, M 1866/90 susceptible to Race 1 was resistant to Race 2.
Resistance trials to Race 2 from 1998–2007 showed that the ratings were consistent for most of the clones across two or more sites where the varieties were evaluated. However, in 196 cases (22%), the reactions were variable. Overall, the percentage of promising clones immune, resistant, slightly susceptible, susceptible and highly susceptible to Race 2 were 14%, 44%, 23%, 13% and 6% respectively (Figure 1). Combining immune, resistant and slightly susceptible reactions, more than 80% of the varieties had adequate resistance to Race 2.

![Fig. 1—Summary of reaction of clones to Race 2 of gumming disease evaluated from 1998–2007.](image)

**Collection of isolates and race characterisation**

Two hundred and sixty isolates were collected between 1998 and 2007 from 10 sugarcane varieties and 13 *S. officinarum* clones situated at 11 locations. Isolations on culture media were taken mostly from foliar stripes, as these were the most frequently encountered symptom, but also from systemically infected stalks. In the latter cases, the varieties concerned were *S. officinarum* and the hybrid M 3035/66. Smooth, circular and very mucoid yellow colonies appeared after 3–4 days on sucrose peptone and recognisable as that of *Xa* pv. *vasculorum*.

The race of the pathogen was determined by sub-culturing the colonies from sucrose peptone agar to tube slants of TZC medium, where the bacterium produced dark red colonies. Race 1 could be differentiated by its compact mucoid growth in contrast to the less viscous Race 2 that flowed down the tube after 4–5 days incubation. Pathogenicity tests were used to differentiate Races 1 and 2.

For Race 1 inoculated in *S. officinarum* clones Iscambine Stripe and Senneville, foliar stripes were yellow at first, then turning necrotic along most of the length of the stripe. Leaf chlorosis in noble canes was slight and of rare occurrence, as the infection progressed and became systemic. Race 1 was not capable of causing lasting infection for more than two weeks in hybrid varieties and foliar symptoms eventually disappeared. In contrast, Race 2 produced long yellow stripes and intense leaf chlorosis in hybrids M 147/44, M 377/56 and M 3035/66 and *S. officinarum* clones. None of the two races could infect variety M 31/45.

Of the 260 isolates obtained, 97 of them belonged to Race 1. The race was isolated from *S. officinarum* clones in germplasm collections present at Réduit. It was absent at all other sampling sites, except in one instance in 1998 when it was found in variety R 570 at Quatre Soeurs. It was not
found in subsequent surveys, except at Réduit. Race 2 was not isolated from *Saccharum* hybrids at Réduit but could be isolated from plantations at all other locations.

**Discussion**

In breeding programs across the world, resistance to main diseases is one of the major objectives. In Australia, clones are tested for resistance to diseases such as chlorotic streak, Fiji leaf gall, leaf scald, mosaic, orange rust, pachymetra root rot, ratoon stunt, red rot, smut and yellow spot in disease resistance trials and Final Assessment Trials before being approved for cultivation by the industry (Croft *et al.*, 2000, Croft, *et al.*, 2008, Magarey *et al.*, 2009). In Louisiana and Florida, USA, varieties are evaluated for dry top rot, eye spot, leaf scald, mosaic, ratoon stunt, rust, smut and yellow leaf. In Mauritius, sugarcane varieties are tested against gumming, leaf scald, rust, smut and yellow spot. The general policy is that a variety susceptible to a particular disease is not recommended in an area where the disease is prevalent.

Variety improvement programs aim at crossing parents with adequate resistance to obtain a high proportion of resistant progeny. Nonetheless, owing to the heterozygous polyploid nature of sugarcane, resistance screening is necessary. Resistance is an important component in the management of sugarcane diseases and has proved powerful for controlling gumming disease. Screening needs to take into account the occurrence of variants of the pathogen that exist in the environment. Thus, evaluation of clones to gumming disease was started in Mauritius in 1932 and at that time resistance trials were established against Race 1.

With the appearance of new races, clones were simultaneously screened in 1964 and then in 1982 to Race 2 and Race 3 respectively. Gumming disease is considered to be a serious threat and, during the past 25 years, only two susceptible varieties, M 3035/66 and R 579, have been released in Mauritius for specific localities where the disease is not prevalent. This approach has been instrumental in managing the disease effectively.

In countries such as Brazil and Australia, the cultivation of resistant clones has been successful to the extent that the disease has been eradicated or reduced to low levels. Legislation for the replacement of susceptible varieties by resistant ones has been promulgated in Australia and Mauritius during gumming disease epidemics with positive effects (Ricaud and Autrey, 1989). In Mauritius, with the replacement of variety M 377/56, Race 3, the cause of an epidemic on this variety, can no longer be observed in sugarcane fields.

Data obtained from resistance trials from 1998 to 2007 showed that 99% of clones tested were immune to Race 1. Resistance to Race 2 was also high (58%), reaching over 80% if slightly susceptible varieties are included. However, compared to Race 1, the magnitude of resistant clones was much less. Race 1 occurs mostly at Réduit and, in that respect, this location had been chosen for variety testing against this race.

In contrast, Race 2 is more widely distributed, hence the choice of diverse sites and also as a measure of its importance in commercial fields. Screening against Race 2 at more than one location is justified owing to discrepancies recorded between sites. The final disease rating of a variety to this race is based on the highest score obtained. Surveys conducted during 10 years showed that Race 1 was recovered only once in commercial fields. In contrast, Race 2 was more predominant on *Saccharum* hybrids and is almost exclusively the race isolated from commercial sugarcane fields. The results of screening and race distribution indicate that the potential of Race 1 in causing disease in hybrids is low compared to Race 2.

The marked difference in variety reactions calls for a reassessment of the status of the races of the bacterium. The variability could well be more profound. Races 1 and 2 are distinguishable by several methods, including cultural characteristics, pathogenicity tests, serology, fatty acids profile, restriction fingerprinting and restriction fragment length polymorphisms (Dookun *et al.*, 2000; Saumtally, 1996; Vauterin *et al.*, 1995).
Despite the fact that the occurrence of Race 1 is insignificant in commercial fields and almost all the clones evaluated are resistant, it is proposed to continue screening with regards to the development of new types of varieties, with different genetic background compared to current ones, meant for biomass and fibre production. Furthermore, gumming disease is known to infect palms, broom bamboo, Guatemala grass and maize. A thorough search of $Xa$ pv. *vasculorum* on these hosts would provide a more comprehensive study on race distribution of the pathogen.

**Conclusions**

The establishment of systematic resistance trials to races of the gumming disease pathogen in Mauritius is a unique situation in sugarcane variety screening. The disease reactions of the various clones and island-wide collection of isolates have allowed an assessment of the threat posed by the disease.

The low ability of Race 1 to cause disease in current sugarcane genotypes, the absence of Race 3 in sugarcane fields and an overall decrease in gumming disease pressure during the last 25 years is comforting. Nevertheless, the identification of resistant varieties should continue so as to further decrease inoculum pressure.

**Acknowledgements**

The authors wish to thank Mr S. Sullivan for his participation in disease resistance trials and Dr H. Khoodoo for the collection of isolates from 2005 to 2007.

**REFERENCES**


ÉVALUATION DES CLONES PROMETTEURS DE CANNE À SUCRE À DEUX RACES DE LA BACTÉRIE DE LA GOMMOSE

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MOTS CLÉS: Résistance aux Maladies, Gommose, Canne à Sucre, Xanthomonas Axonopodis Pv. Vasculorum.

Résumé

DEUX RACES de la bactérie de la gommose (Xanthomonas axonopodis pv. vasculorum), Races 1 et 2, causent régulièrement une infection de la canne à sucre à Maurice. Les clones issus du 3ème stade clonal (4–5 années) du programme d’amélioration génétique sont évalués pour leur résistance aux deux races. De 1998 à 2007, 878 clones ont été testés dans des essais d’évaluations dans divers sites où les races sont présentes. Des rangs de canne des variétés sensibles artificiellement inoculées agissaient comme source de dissémination de la maladie aux variétés en évaluation. Le criblage à la Race 1 fut effectué sur un site et sur deux à quatre sites pour la Race 2. Les résultats de ces essais ont montré que 99% des clones étaient immunes à la Race 1. Des 9 clones qui étaient infectés à divers degrés, sept étaient résistants, un légèrement sensible et un sensible. Le pourcentage de clones démontrant une immunité à la Race 2 était bien plus faible (14%). Les pourcentages de clones résistants, légèrement sensibles, sensibles et très sensibles étaient de 44%, 23%, 13% et 6% respectivement. L’évaluation était consistante d’un site à l’autre pour 78% des clones. L’établissement des essais sur plus d’un site est conséquemment nécessaire pour une évaluation fiable. Le pathogène a été isolé des champs industriels dans les régions où la maladie est présente ainsi que dans les collections du germoplasme pendant la période 1997–2007. La race de la bactérie fut déterminée sur la base des caractéristiques en milieux de culture et des tests de pathogénicité. La Race 1 était couramment isolée des cannes nobles conservées en collection. À part un cas en 1998, cette race était absente des champs commerciaux. Ces prospections ont confirmé que les variétés industrielles étaient très résistantes à la Race 1 et elle était de ce fait, d’importance mineure. La maladie de la gommose présente dans les champs industriels était donc presque exclusivement causée par la Race 2. Le criblage des variétés contre la Race 2 dans différents environnements est conséquemment nécessaire.
ESQUEMA DE RESISTENCIA A LA GOMÓSIS BACTERIANA EN CLONES AVANZADOS DE CAÑA DE AZÚCAR

Por

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Palabras clave: Resistencia a Enfermedades, Gomósis de la Caña de Azúcar, Xanthomonas axonopodis pv. vasculorum.

Resumen
EXISTEN DOS RAZAS de la bacteria causal de la gomósis (Xanthomonas axonopodis pv. vasculorum), razas 1 y 2 que comúnmente infectan a las variedades de caña de azúcar en Mauricio. Los clones seleccionados en el tercer estado clonal (a los 4–5 años) del programa de mejoramiento son examinados para detectar la resistencia a estas dos razas. Desde 1998 hasta 2007, 878 clones fueron evaluados en ensayos de resistencia en las localidades donde son más frecuentes las dos razas. Surcos de una variedad susceptible se inocularon para que se constituyeran en fuente de inóculo para las variedades de la prueba. La evaluación contra la raza 1 se llevó a cabo en un sitio, mientras que contra la raza 2 se llevó a cabo en dos a cuatro sitios. Los resultados mostraron que el 99% de los clones fueron inmunes a la raza 1. De los 9 clones que mostraron infección, siete fueron clasificados como resistentes, uno como levemente susceptible y uno como susceptible. En contraste, el porcentaje de los clones que mostraron inmunidad a la raza 2 fue mucho menor (14%). La resistencia, levemente susceptible, susceptible, y alta susceptibilidad a la raza 2 en el resto de los clones fue de 44%, 23%, 13% y 6%, respectivamente. Las calificaciones fueron consistentes entre localidades para el 78% de los clones. La evaluación en más de un sitio por tanto se justificó. El patógeno siempre se aisló en los campos comerciales en las regiones propensas a la enfermedad y en las colecciones de germoplasma durante el período 1998–2007. La caracterización de las razas se basó en las características culturales y pruebas de patogenicidad. La raza 1 se ha aislado continuamente en colecciones de cultivares nobles de caña. Excepto por un caso en 1998, siempre ha estado ausente en los campos comerciales. Estos estudios confirmaron que las variedades comerciales son altamente resistentes a la raza 1 y, por tanto, de poca importancia para los híbridos de Saccharum. La presencia de la gomósis en las plantaciones comerciales es exclusiva de la raza 2, por tanto, su detección y evaluación por resistencia en contra de ella en diferentes ambientes se considera necesario.
DISTRIBUTION OF SUGARCANE YELLOW LEAF VIRUS (SCYLV) IN COMMERCIAL CULTIVARS IN MAURITIUS AND ITS POTENTIAL IMPACT ON YIELD

By

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KEYWORDS: Luteovirus, Melanaphis sacchari, Saccharum officinarum, Yellow Leaf, Yield Loss.

Abstract

Sugarcane yellow leaf virus (ScYLV) is present in most sugarcane producing countries and has been shown to be the cause of yellow leaf disease of sugarcane. This study focused on the distribution of ScYLV in commercial sugarcane varieties in Mauritius and attempted to assess its impact on cane and sucrose yields of three varieties: M52/78 (early maturing), M1400/86 (middle maturing) and M2593/92 (late maturing). An island-wide survey of 88 fields planted with 20 different varieties revealed that ScYLV was widely distributed in all varieties except M1176/77 which always tested negative for the presence of the virus by tissue blot immunoassay (TBlIA) and reverse transcriptase PCR. The incidence of ScYLV did not reflect that of the aphid vector Melanaphis sacchari which was collected from 8% of fields only, implying that the main cause of the spread of the virus in Mauritius was infected cane setts. The potential impact of yellow leaf on Mauritian cultivars was assessed by measuring and comparing yield parameters of TBlIA positive and TBlIA negative cane stool samples in a pair wise design under commercial field conditions. This study showed that, for plant cane, yields were comparable for varieties M52/78, M1400/86 while, in M2593/92, TBlIA positive stools had higher sucrose content but lower weight than TBlIA negative stools. These findings highlight the need for additional research on the main commercial varieties of sugarcane in order to determine the economic importance of the disease in Mauritius.

Introduction

Yellow leaf of sugarcane is caused by Sugarcane yellow leaf virus (ScYLV) and has been reported in many sugarcane producing countries (Lockhart and Cronjé, 2000). The virus is classified as a polerovirus of the family Luteoviridae (D’Arcy and Domier, 2005) and is transmissible by aphid vectors and infected seed cane (Schenck and Lehrer, 2000; Zhou et al., 2006). Previous reports on the occurrence of yellow leaf of sugarcane estimated the potential yield losses in the range of 10–40% (Vega et al., 1997; Lockhart and Cronjé, 2000; Grisham et al., 2002). It is generally agreed that yields of different genotypes of sugarcane are affected at varying extents under different climatic conditions. Differences in virulence and infection capacity of different genotypes of the polerovirus have also been reported (Abu Ahmad et al., 2007). While some cultivars, such as H78-4153 (Schenck and Lehrer, 2000), are considered as resistant to the disease, others such as SP71-6163 and R577 (Rassaby, 2001) have been shown to have reduced sugar yields by as much as 20% compared to virus-free canes. Of the commercial varieties of sugarcane cultivated on 64 000 ha in Mauritius, the distribution of ScYLV and varietal responses to yellow leaf locally were undefined with the exception of M1658/78 and M695/69 which have been assessed in a previous study (Moutia and Saumtally, 1999). The varietal responses for R570, R575 and R579, which are also planted in Mauritius, have been studied in Reunion Island (Rassaby, 2001; Rassaby et al., 2004; Abu Ahmad et al., 2007). The epidemiology and effect on yield of the
disease have not been established in Mauritius. The relative importance of vegetative propagation or vectors in the spread of the disease is not known. The occurrence of aphids is believed to be low in sugarcane fields, but their distribution and identity needs to be ascertained.

Materials and methods

Distribution of ScYLV

An island-wide survey was undertaken and leaf samples of 20 commercial varieties were collected from 88 fields visited randomly at 25 sites, covering all sugarcane growing areas as well as climate and soil types. The youngest completely unrolled leaves (F1) were sampled across the fields in a zigzag pattern. Between 26 and 251 leaves were collected per site, depending on area and variety distribution. A total of 3008 leaves were sampled. The plants sampled were checked for aphid species Melanaphis sacchari (Zehnt) and Rhopalosiphum maidis (Fitch), known to have the potential to transmit ScYLV. An overall rating was given to the infection levels in the fields surveyed based on the occurrence of disease symptoms. A scale of 0 to 3 (Table 1; Figure 1) was used to rate the severity of typical symptoms of yellow leaf.

TBIA and RT-PCR

Leaves were tested by tissue blot immunoassays (TBIA) using a cross-absorbed polyclonal antibody developed at the Mauritius Sugar Industry Research Institute (MSIRI) (D08, Y. Moutia) and the technique developed by Schenck et al. (1997). Confirmatory tests were carried out on subsamples by reverse transcriptase PCR on extracts of total nucleic acids (Joomun and Dookun-Saunttally, 2008).

Yield loss assessment

Three plant cane fields of an early maturing variety (M52/78), a middle variety (M1400/86), and a late harvest variety (M2593/92) were chosen for the evaluation of the impact on yields. Fields were chosen taking into consideration cultural parameters such as irrigation and slope to ensure minimum field variation among the selected stools. The choice was also based on known incidence of yellow leaf from data gathered in the survey. Selected fields were those where the probability of finding virus-free stools was reasonably high (>15 %) to allow the analysis to be carried out in a
pair wise design. The sites were Mon Desert Alma (field 114), Henrietta (field 7278) and St Antoine (field 5025) for M52/78, M1400/86 and M2593/92 respectively.

Cane stools were tested by TBIA to differentiate between stools that were free from the disease and those that were infected. Two F1 leaves were sampled from each stool, one from the primary stalk and one from the youngest stalk. Three hundred and eighty five stools were individually tested by TBIA.

Once the ScYLV negative stools had been identified, they were tagged (stools A) in the field and the next ScYLV positive stool in the same cane row was tagged as a paired sample (stools B). Stools were hand cut at the base and individual millable stalks were measured in length (up to the top visible dewlap) and diameter (at the centre of the stalk) prior to the whole stool being weighed and sent to the mill where brix, pol and fibre parameters were determined.

Statistical significance of differences in means of yield parameters between ScYLV positive and ScYLV negative stools were determined by carrying out one-way pair wise T-tests at 90% (P<0.01) and 95% (P<0.005) confidence for the respective pairs of stools. This analysis was performed using the GenStat Discovery 7th Edition (DE3) software.

**Table 1**—Scoring scale for the severity of yellow leaf

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No yellowing</td>
</tr>
<tr>
<td>1</td>
<td>Midrib yellow, green lamina</td>
</tr>
<tr>
<td>2</td>
<td>Midrib yellow, lamina turning yellow, slight necrosis of the leaf tip</td>
</tr>
<tr>
<td>3</td>
<td>Midrib completely yellow, turning orange/red, lamina yellow, showing necrosis from tip downwards</td>
</tr>
</tbody>
</table>

**Results**

**Survey of the incidence of ScYLV in local commercial varieties of sugarcane**

The survey revealed that ScYLV is widely distributed in Mauritius being prevalent in all commercial varieties tested except for M1176/77 (Figure 2).
Variety M1176/77 always tested negative for the presence of ScYLV both by TBIA and RT-PCR. Variety R573 showed a comparatively low percentage of infection (6% of samples from 10 different fields) although leaf symptoms were observed (score 2; Table 2). A similar observation was made for variety M52/78 in one field at Britannia, in the south of the island, where severe symptoms (score 3) correlated with a low percentage infection (5%). This variety was the third least infected variety sampled with 28.8% of samples tested positive by TBIA. Variety M1551/80 also tested negative for ScYLV but only one field was tested.

Severe symptoms (score 3) of the disease were observed in varieties M387/85, M 95/69, M703/89, M1186/86, M1400/86, M2024/88, M2593/92, R570, R573 and R575 but the symptom severity varied for different ratoon stages and locations. Among these varieties, R570, R573, M52/78 and M1400/86 did not show any symptom of yellow leaf (score 0) in some fields. Out of 88 fields that were visited, 50 exhibited asymptomatic canes but had a high level of infection with a mean of 58% plants testing positive with TBIA.

The maize aphid *R. maidis* was not observed in any of the fields visited. *Melanaphis sacchari* were observed in 10 fields in 8 sites only (Figure 2). The incidence of aphids was low in the fields visited (8%) and only one field at Joli Bois (Savannah, south of Mauritius) was severely infested with hundreds of aphids collected.

Table 2—Presence of ScYLV in commercial sugarcane varieties as determined by tissue-blot immunoassay and the average score for symptoms.

<table>
<thead>
<tr>
<th>Commercial variety</th>
<th>% coverage of commercial plots in Mauritius</th>
<th>No. Fields sampled</th>
<th>% positive samples in TBIA tests</th>
<th>Average score of observed symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>M 2024/88</td>
<td>0.17</td>
<td>1</td>
<td>100.0</td>
<td>3</td>
</tr>
<tr>
<td>M 1246/84</td>
<td>2.25</td>
<td>5</td>
<td>49.3</td>
<td>2</td>
</tr>
<tr>
<td>M 1400/86</td>
<td>10.26</td>
<td>18</td>
<td>74.7</td>
<td>1</td>
</tr>
<tr>
<td>M 3035/66</td>
<td>5.62</td>
<td>2</td>
<td>50.0</td>
<td>3</td>
</tr>
<tr>
<td>M 52/78</td>
<td>6.40</td>
<td>11</td>
<td>28.8</td>
<td>3</td>
</tr>
<tr>
<td>M 1176/77</td>
<td>13.24</td>
<td>8</td>
<td>0.0</td>
<td>0</td>
</tr>
<tr>
<td>M 1186/86</td>
<td>0.61</td>
<td>1</td>
<td>100.0</td>
<td>3</td>
</tr>
<tr>
<td>R 570</td>
<td>20.50</td>
<td>8</td>
<td>50.9</td>
<td>1</td>
</tr>
<tr>
<td>R 573</td>
<td>7.15</td>
<td>10</td>
<td>6.0</td>
<td>2</td>
</tr>
<tr>
<td>R 579</td>
<td>8.12</td>
<td>15</td>
<td>99.2</td>
<td>1</td>
</tr>
<tr>
<td>R 575</td>
<td>6.07</td>
<td>5</td>
<td>69.5</td>
<td>2</td>
</tr>
<tr>
<td>M 703/89</td>
<td>0.89</td>
<td>8</td>
<td>97.8</td>
<td>3</td>
</tr>
<tr>
<td>M 2593/92</td>
<td>0.01</td>
<td>4</td>
<td>55.1</td>
<td>3</td>
</tr>
<tr>
<td>M 1394/86</td>
<td>0.45</td>
<td>1</td>
<td>23.0</td>
<td>2</td>
</tr>
<tr>
<td>M 387/85</td>
<td>1.33</td>
<td>4</td>
<td>94.2</td>
<td>3</td>
</tr>
<tr>
<td>M 555/60</td>
<td>0.30</td>
<td>1</td>
<td>5.6</td>
<td>2</td>
</tr>
<tr>
<td>M 2256/88</td>
<td>0.36</td>
<td>1</td>
<td>8.1</td>
<td>1</td>
</tr>
<tr>
<td>M 1551/80</td>
<td>0.40</td>
<td>1</td>
<td>0.0</td>
<td>0</td>
</tr>
<tr>
<td>M 1861/89</td>
<td>0.01</td>
<td>1</td>
<td>100.0</td>
<td>2</td>
</tr>
<tr>
<td>M 695/69</td>
<td>9.45</td>
<td>2</td>
<td>100.0</td>
<td>3</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td>50.9</td>
<td>NA</td>
</tr>
</tbody>
</table>

*2006 Figures (MSIRI)
NA: not applicable

The impact of ScYLV on yield

One hundred stools of M52/78 were analysed and 32 tested negative in TBIA. Sixteen pairs of stools were compared and the statistical t tests carried out showed that there were no significant differences between the mean values of each of the yield parameters for this variety. Similarly, 165
stools of variety M1400/86 were tested by TBIA and 31 stools (18.8%) tested negative for ScYLV. Apart from the mean diameter of stalks which was 1.2% significantly greater at \( p<0.01 \) in TBIA negative stools than in TBIA positive stools, none of the other differences in means were statistically significant at 95% confidence. Hence, under the prevailing conditions, no significant differences were found between the yields of TBIA positive and TBIA negative stools for this variety.

For variety M2593/92, 120 stools were initially tested by TBIA and 61 stools (50.8%) tested negative for ScYLV. Table 3 summarises the results of the cane analysis and the derived yield indicators. TBIA negative stools and TBIA positive stools were not significantly different for average fresh weight per stool or average stalks per stool.

Canes from TBIA negative stools had greater mean lengths (3.25%, \( p=0.031 \)) and diameters (2.87%, \( p=0.01 \)) than TBIA positive stools. Canes from TBIA positive stools had a higher sucrose content than TBIA negative stools as shown by the Pol % Cane (+3.4%, \( p=0.016 \)), Brix (+2.4%, \( p=0.035 \)) and IRSC (+3.9%, \( p=0.016 \)). There were no significant differences between TBIA negative and TBIA positive stools for sugar content/stool, Pol % dry matter values (Pol % DM), % fibre or % dry matter.

### Table 3—Yield parameters in TBIA negative and TBIA positive stools of M2593/92 at St Antoine.

<table>
<thead>
<tr>
<th></th>
<th>TBIA negative</th>
<th>Std error</th>
<th>TBIA positive</th>
<th>Std error</th>
<th>% diff.</th>
<th>Sig. at 95% confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average fresh weight/stool (kg)</td>
<td>11.30</td>
<td>0.48</td>
<td>10.40</td>
<td>0.40</td>
<td>8.68</td>
<td>ns</td>
</tr>
<tr>
<td>Average no stalks/stool</td>
<td>9.16</td>
<td>0.35</td>
<td>9.03</td>
<td>0.26</td>
<td>1.41</td>
<td>ns</td>
</tr>
<tr>
<td>Average length (cm)</td>
<td>248.73</td>
<td>2.05</td>
<td>240.91</td>
<td>2.27</td>
<td>3.25</td>
<td>s</td>
</tr>
<tr>
<td>Average diameter (mm)</td>
<td>24.21</td>
<td>0.17</td>
<td>23.54</td>
<td>0.19</td>
<td>2.87</td>
<td>s</td>
</tr>
<tr>
<td>Average Pol % Cane</td>
<td>13.81</td>
<td>0.14</td>
<td>14.28</td>
<td>0.13</td>
<td>–3.39</td>
<td>s</td>
</tr>
<tr>
<td>Average IRSC^a</td>
<td>10.09</td>
<td>0.12</td>
<td>10.49</td>
<td>0.11</td>
<td>–3.94</td>
<td>s</td>
</tr>
<tr>
<td>Average sugar content/stool (kg)</td>
<td>1.14</td>
<td>0.05</td>
<td>1.09</td>
<td>0.05</td>
<td>4.09</td>
<td>ns</td>
</tr>
<tr>
<td>Average Brix</td>
<td>4.01</td>
<td>0.04</td>
<td>4.11</td>
<td>0.03</td>
<td>–2.35</td>
<td>s</td>
</tr>
<tr>
<td>Average Fibre % Cane</td>
<td>13.09</td>
<td>0.35</td>
<td>13.04</td>
<td>0.19</td>
<td>0.35</td>
<td>ns</td>
</tr>
<tr>
<td>Average DM^b % Cane</td>
<td>28.77</td>
<td>0.38</td>
<td>29.10</td>
<td>0.21</td>
<td>–1.12</td>
<td>ns</td>
</tr>
<tr>
<td>Average Pol % DM</td>
<td>48.15</td>
<td>0.58</td>
<td>49.10</td>
<td>0.41</td>
<td>–1.97</td>
<td>ns</td>
</tr>
<tr>
<td>Average Fibre % DM</td>
<td>45.32</td>
<td>0.61</td>
<td>44.77</td>
<td>0.42</td>
<td>1.24</td>
<td>ns</td>
</tr>
</tbody>
</table>

^a Industrially recoverable sucrose content  
^b dry matter  
s: statistically significant, \( P<0.05 \)  
ns: not statistically significant, \( P>0.05 \)

### Discussion

Results from the survey on the incidence of ScYLV in different locations revealed that environmental effects were minimal and the distribution of the virus was related to the variety grown. The high percentage of infected canes in commercial fields planted in 2006 and 2007 and the low occurrence of aphid vectors in these fields possibly imply that the main source of propagation of ScYLV is via systemically infected cane setts. However, as aphid populations vary greatly during the season, monitoring over a longer period is necessary to draw meaningful conclusion. The spread of viral infection to neighbouring plants by aphids has been observed to be relatively slow and in the range of a few metres per year (Lehrer et al., 2007). Rassaby et al. (2004) also reached the conclusion that the virus is mainly propagated by planting infected cuttings. This is
further supported by the fact that recently released cane varieties showed high incidence of the virus in the absence of aphid vectors [M703/89 (97.8%), M1400/86 (74.7%), M2593/92 (55.1%)]. The incidence of the virus in R570, the main variety planted in Mauritius, was 50.9%, which correlates well with previous studies carried out in Reunion Island (Rassaby et al., 2004; Abu Ahmad et al., 2007). Varieties R579 and M703/89 are popular with sugarcane growers in Mauritius and they showed a ScYLV incidence as high as 98–100%. It was practically impossible to compare virus-free and infected stools in commercial fields planted with these varieties because of the high incidence of disease. Such a comparison would require generating clean material by \textit{in vitro} meristem cultures.

The sampling method and paired design for the yield loss assessment ensured that the inherent variations in the field were minimal. Results showed that variety M2593/92 could be more susceptible to yellow leaf than M52/78 and M1400/86 as it exhibited severe foliar symptoms (score 3). Yield parameters for the latter two varieties were comparable for healthy and infected stools; therefore, these varieties could be rated tolerant to yellow leaf in plant cane.

M2593/92 had higher sucrose content in stalks from infected stools than for TBIA negative stools. This observation does not agree with previous reports on other varieties where yellow leaf was associated with reductions in sucrose content in stalks and 10–40% decreases in cane yield (Vega et al., 1997; Lockhart and Cronjé, 2000; Grisham et al., 2002).

In this study, the tonnage of variety M2593/92 was 8.68% greater for TBIA negative stools while the decrease in yield of TBIA positive stools was compensated by higher recoverable sucrose content (+3.94 in IRSC, p=0.016, Table 3), resulting in a buffering effect of the potential loss in the yield of sugar in infected stools. The difference in tonnage was lower (8.68%) than that typically reported and could be attributed to the specific varietal response to infection under the prevailing conditions of the study.

During the maturation period of sugarcane, vegetative growth is balanced with sucrose accumulation. The increase in sucrose content in infected stools of M2593/92 could be attributed to a decrease in vegetative growth in favour of sucrose accumulation, typical of luteovirus infections (Harrison, 1999), as shown by the decrease in average length and diameter of stalks of diseased stools (Table 3).

Infection by ScYLV has been found to cause alteration in photosynthetic metabolism and plant carbohydrate metabolism (Gonçalves et al., 2005) and similar observations in susceptible varieties have been made previously for varieties M1658/78 and S17 (J-F. Y. Moutia, pers. comm.). The increase in sucrose content of susceptible varieties is not expected to constitute an increase in the yield of sugar of infected fields because the resultant effect would be that the genetic potential of the variety would not be achieved, since the stunting would reduce stalk development and metabolic disturbances would result in accumulation of reducing sugars in leaves. This increase in reducing sugars in juice (Fontaniella et al., 2003) would negatively impact upon the juice quality.

Since canes do not recover from infections (Rassaby et al., 2004), a cumulative increase in viral titre from the primary infection, notwithstanding localised aphid infestation patterns (McAllister et al., 2008), could hypothetically cause more pronounced losses in tonnage and yields of sugar in older ratoons than in plant canes. Rassaby et al. (2002) observed a reduction in stalk height, cane diameter, weight and sugar content in cultivar R577 but not in cultivars R570 and R579 in plant cane. The impact of the disease was higher in the first ratoon.

**Conclusions**

Yellow leaf is a complex disease and interactions among different parameters such as abiotic and biotic stress, virus genotype (Abu Ahmad et al., 2007), physiological age, plant genetic resistance and ratooning need to be studied more closely. A precautionary approach should be adopted while assessing the varietal resistance based on symptoms. While the extremes (highly resistant, e.g. M1176/77 and highly susceptible, e.g. M695/69) are more consistently defined, the
middle range of varieties constitute a challenge for precise ratings due to their differential response to infection under varying conditions.

The present study updated the information on the distribution of ScYLV in the main commercial cane varieties and attempted to assess its potential impact on yield of three popular varieties in Mauritius under commercial field conditions. The virus was detected in 18 out of 20 varieties, showing that current cultivars could be extensively infected. Variety M1176/77 appeared to be resistant as none of the 275 samples tested was infected. It is a potential parent in the development of resistant varieties. No yield loss was observed in the evaluation, but it is necessary to conduct a more in-depth study using diseased compared with disease-free planting material established in separate plots to assess the effect. The ScYLV strain has also to be taken into account. Only the REU strain, least virulent, has been observed in commercial varieties (Joomun and Dookun-Saumtally, 2008). A management strategy for yellow leaf disease in Mauritius should also comprise the development of clean nurseries that could include, if necessary, planting field borders with resistant varieties and spraying aphicides within these borders during the peak period of aphid movement.

Acknowledgements

The authors wish to thank Mr J-F. Y. Moutia for supplying the polyclonal anti- ScYLV antibody used in the TBIA and Mr N. Joomun for carrying out confirmatory tests by RT-PCR.

REFERENCES


DISTRIBUTION DU SUGARCANE YELLOW LEAF VIRUS (SCYLV) DANS LES VARIÉTÉS COMMERCIALES À MAURICE ET SON IMPACTE POTENTIEL SUR LE RENDEMENT

Par

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MOTS-CLES: Luteovirus, Melanaphis sacchari, Saccharum officinal, Feuille Jaune, Pertes de Rendement.

Le Sugarcane yellow leaf virus (ScYLV), agent causal de la maladie de la feuille jaune, est fréquemment observé dans la plupart des pays producteurs de canne à sucre. Cette étude met l’emphase sur la distribution du virus dans les variétés commerciales mauriciennes et tente d’évaluer l’impacte potentiel de la maladie sur les rendements en canne et en sucre de trois variétés, la M 52/78 (maturation tôt dans la saison), la M 1400/86 (maturation en milieu de saison) et la M 2593/92 (maturation en fin de saison). Un échantillonnage de 88 champs établis dans 20 régions différentes de l’île a révélé que le ScYLV était présent dans toutes les variétés testées sauf la M
1176/77 qui fut testée par les techniques d’immuno empreintes (TBIA) et RT-PCR. L’incidence du virus ne corrobore pas à la distribution du puceron, *Melanaphis sacchari*, (seulement 8% des champs étaient infestés par le vecteur), suggérant que la cause principale de la transmission du virus à Maurice est par boutures infectées. L’impacte potentiel du virus sur le rendement fut analysé en comparant différents paramètres de rendement entre des pairs de fossés infectés et non infectées de champs commerciaux. les feuilles provenant de ces fossés étant au préalable testés par le TBIA. Cette étude a démontré que, pour la cane vierge, les remènements entre la canne infectée et non Infectée étaient comparables pour les variétés qui mûrisissent tot et en milieu de saison. Pour la variété tardive M 2593/92, les fossés malades étaient plus riches en saccharose que les fossés sains. L’impacte potentiel de la maladie de la feuille jaune sur la cane à sucre à Maurice fut déduit en considérant les récentes publications ainsi que les observations faites pendant cette étude. Ces résultats suscitent l’intérêt pour plus de recherche sur l’impacte de la maladie sur les variétés commerciales afin d’en déduire les retombées économiques.

**DISTRIBUTION OF SUGARCANE YELLOW LEAF VIRUS (SCYLV) EN CULTIVARES COMERCIALES EN MAURICIO Y SU IMPACTO POTENCIAL E LA PRODUCCIÓN**

Por

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**Resumen**

El virus de la hoja amarilla (ScYLV) se encuentra presente en la mayoría de los países productores de caña de azúcar y se ha demostrado ser la causa de la enfermedad de hoja amarilla de la caña de azúcar. El presente estudio se centró en la distribución de SCYLV en variedades comerciales de caña de azúcar en Mauricio y trató de evaluar su impacto en las producciones de caña y sacarosa de tres variedades: M52/78 (maduración temprana), M1400/86 (maduración media) y M2593/92 (maduración tardía). Un estudio a escala de la isla en 88 campos sembrados con 20 variedades diferentes, mostró que SCYLV se distribuyó ampliamente en todas las variedades excepto M1176/77, que siempre resultó negativa a la presencia del virus mediante pruebas inmunológicas del Tissue Blot (TBIA) y amplificación por PCR. En Mauricio, el áfido vector *Melanaphis sacchari* se encontró solamente en el 8% de los campos, lo que indica que la causa principal de la propagación del virus en los campos comerciales es el uso de semilla infectada. El impacto potencial de la hoja amarilla en cultivares de Mauricio se evaluó mediante la medición y comparación de los parámetros de producción de cepas TBIA positivas y y TBIA negativas en un diseño apareado en condiciones de campo comercial. Este estudio mostró que, para la caña plantilla, las producciones fueron comparables para las variedades M52/78, M1400/86, mientras que en M2593/92, las cepas TBIA positivas tuvieron un contenido de sacarosa superior y menor peso que las cepas TBIA negativas. Estos resultados destacan la necesidad de investigación adicional sobre las principales variedades comerciales de caña de azúcar con el fin de determinar la importancia económica de la enfermedad en Mauricio.
IDENTIFICATION OF SOURCES OF RESISTANCE TO SUGARCANE RED ROT

By

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KEYWORDS: Saccharum, Colletotrichum falcatum, Glomerella.

Abstract

RED ROT, caused by Colletotrichum falcatum Went, adversely affects sugarcane stand establishment in Louisiana by rotting planted stalks. Since cultivar resistance is the most effective control method, a study was conducted to identify sources of resistance to red rot and evaluate variability within Saccharum species and Erianthus. Saccharum spontaneum, S. robustum, S. sinense, S. officinarum, S. barberi, and Erianthus clonal accessions were evaluated for resistance alongside susceptible commercial cultivars in three experiments. Harvested stalks were inoculated with C. falcatum. Following a 6-week incubation, each stalk was split and rated for red rot symptoms including number of nodes passed (NP), number of nodes rotted (NR), internode rot severity (IRS), and a rot index (RI) that takes into account both the extent of node damage and internode rot. Significant differences were detected among species and accessions within species for all traits. Among the Saccharum species, S. barberi, S. robustum and S. spontaneum exhibited the lowest red rot symptom severity means, while S. officinarum and S. sinense had the highest severity means. A high level of variation was observed within S. spontaneum with RI means ranging from two to 29. Three of 31 S. spontaneum accessions (10%) had an NR mean less than 5, and 26% had a mean less than 10. S. barberi exhibited a high level of resistance, with RI means ranging from one to 20. Four of 14 S. barberi accessions (29%) had an RI mean of less than 5 (highly resistant), and six (43%) had a mean of 10 or less (moderately resistant). The least amount of variation was seen among the Erianthus accessions, with all showing little, if any, red rot symptoms. The Erianthus genus possesses high resistance and should be used as parental material in breeding programs where enhanced red rot resistance is needed. Other more easily utilised sources of resistance to red rot within the Saccharum germplasm are selected S. spontaneum and S. barberi accessions.

Introduction

Red rot, caused by Colletotrichum falcatum Went, damages sugarcane (inter-specific hybrids of Saccharum L.) by rotting standing cane and planted stalks (Singh and Lal, 2000). In Louisiana, red rot adversely affects stand establishment by rotting planted seedcane (Abbott, 1938). Red rot is difficult to control through hot-water and fungicide treatments (Singh et al., 2008). Therefore, the disease is controlled with host plant resistance. A heritability study conducted in Louisiana indicated that resistance can be increased by careful cross-based selection (Yin et al., 1994). However, an additional finding of this study was that the frequency of resistance was low within both breeding and selection populations. The results suggested that the introgression of genes from related wild germplasm might be needed to enhance red rot resistance in the parent population.
In India, a high frequency of resistance was demonstrated among *S. spontaneum* clones (Satyavir *et al.*, 1994; Srinivasan and Alexander, 1971). The objectives of this study were to identify sources of red rot resistance in *Saccharum* species and *Erianthus* that might be utilised in future breeding efforts to develop resistant cultivars and evaluate variability in resistance within this material.

### Materials and methods

Resistance screening experiments were conducted in 2004, 2005, and 2008. A total of 90 *Saccharum* and nine *Erianthus* clonal accessions were evaluated for resistance to sugarcane red rot. The accessions evaluated are part of a collection maintained at the USDA-ARS Sugarcane Research Unit, Houma, LA. *Saccharum* accessions tested represented five species, as well as a limited number of commercial sugarcane cultivars (Table 1). Variable numbers of accessions were evaluated each year. Accessions in *Erianthus* included four *E. arundinaceus*, two *E. bengalense*, and one each of *E. procerus* and *E. ravennae*.

Data were assessed yearly to determine if there were differences between species and among clones within each species during any given year. In addition, a set of clones from each of the *Saccharum* species was included in a multi-year analysis to determine genotype, environment, and genotype x environment interactions. Fourteen *S. barberi*, 11 *S. sinense*, seven *S. officinarum*, seven *S. robustum*, and 31 *S. spontaneum* clones were analysed in 2004 and 2008 along with the susceptible commercial cultivar LCP85-384. The screening population varied among experiments, and not all clones were included in the multi-year analysis due to the lack of some materials for additional testing and the receipt of new imports into the collection as the study progressed.

### Table 1—Number of *Saccharum* and *Erianthus* accessions screened for resistance to red rot in 2004, 2005, and 2008, and across all three years (Total number). A multi-year analysis was conducted on a subset of *Saccharum* clones in 2004 and 2008.

<table>
<thead>
<tr>
<th>Accession type</th>
<th>Total number</th>
<th>2004</th>
<th>2005</th>
<th>2008</th>
<th>2004 and 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial hybrid</td>
<td>6</td>
<td>1</td>
<td>6</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td><em>Erianthus</em> spp.</td>
<td>9</td>
<td>1</td>
<td>9</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td><em>S. barberi</em></td>
<td>17</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td><em>S. officinarum</em></td>
<td>9</td>
<td>9</td>
<td>3</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td><em>S. sinense</em></td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td><em>S. robustum</em></td>
<td>11</td>
<td>9</td>
<td>0</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td><em>S. spontaneum</em></td>
<td>36</td>
<td>32</td>
<td>26</td>
<td>33</td>
<td>31</td>
</tr>
</tbody>
</table>

The accessions were planted in February 2004, 2005, and 2008 from nodal cuttings and grown in 37.8 L containers in a soil-less potting medium. In December of each year, four undamaged stalks of each accession were cut, and the leaves were removed. Stalks were then dipped in a 0.26% solution of sodium hypochlorite for 10 minutes to surface disinfect and they were inoculated with *C. falcatum*. A 3.2-mm-diameter hole was drilled into, but not through, the centre internode of all four stalks of each accession, and 100 μL of a conidial suspension of *C. falcatum* (3.8 x 10⁸ spores/mL) was introduced. Stalks were wrapped inside a perforated sheet of polyethylene and kept moist for 6 weeks at room temperature. Following incubation, all stalks were split longitudinally and assessed for disease severity. Each stalk was rated for the following symptoms: i) number of nodes passed (NP) by internode rot symptoms in each direction from the inoculation point, ii) number of nodes exhibiting rot symptoms (NR), and iii) internode rot severity (IRS) in each internode, including the one inoculated and three in either direction. IRS was visually rated 1–6 based on the amount of rot observed in each internode, where 1 ≤ 10%, 2 = 11 to 25%, 3 = 26 to 50%, 4 = 51 to 75%, 5 = 76 to 90%, and 6 > 90% of the internode tissue exhibited red discoloration. A single IRS rating was given to each stalk by averaging the seven internodes.
assessed. A rot index (RI) was calculated based on a combination of traits. It was calculated as $RI = (NP + NR) \times \log_{10} (IRS+1)$.

The effect of species and accession on red rot susceptibility was determined by analysis of variance using the PROC MIXED procedure in SAS (SAS Institute, 2001) with replication and years as random variables. Differences between species and accession least square means were compared using the pdiff option (Saxton, 1988) at the 0.05 probability level.

**Results and discussion**

A species effect was found for all four traits analysed in all three single-year analyses. In 2004, differences were found among clones within all *Saccharum* species for all traits analysed. The single *Erianthus* accession included in the 2004 analysis was more resistant than the average of other species for all traits. On average, *S. robustum* and *S. barberi* were the most resistant of the *Saccharum* species. In 2005, less significance was seen among the accessions within species. For every trait, all nine *Erianthus* clones showed near complete resistance to red rot. This resulted in a lack of significance among accessions within this genus, and the *Erianthus* genus, as a whole, was more resistant than all the *Saccharum* species. Despite the relatively large number of *S. sinense* clones (11) included in 2005, the only traits showing significant differences among the clones were NR and RI. A lack of significance was observed among the three *S. officinarum* clones for NP, NR, and RI in 2005, but this could be an artifact of the low sample size and does not necessarily indicate a lack of overall variation within the species. Differences were detected for all traits among clones within *S. barberi* and *S. spontaneum*. In 2008, *Erianthus* again showed complete resistance, while all other species showed differences among accessions.

This study did not attempt to evaluate variability in resistance within commercial cultivars. A previous study (Yin *et al*., 1994) found a high frequency of susceptibility in the current cultivar population.

When data from all three years were combined, differences were found among species for NP, NR, IRS and RI. The nine *Erianthus* clones showed near complete resistance and were more resistant than the other species for all four traits. The species were ranked in order of average resistance for each of the four measured traits, and these rankings were summed to give an overall ranking of resistance. The order of overall ranking was as follows: *Erianthus* > *S. robustum* > *S. barberi* > *S. spontaneum* > *S. sinense* and *S. officinarum* > commercial sugarcane (hybrid clones). While the number of clones per species in the combined 3-year data set was unbalanced, it gave a general idea of relative resistance among the species.

A subset of each of the *Saccharum* species and the commercial sugarcane cultivar LCP85-384 were included in a 2004 and 2008 multi-year analysis to determine significant genotype, year, and genotype by year interactions. Significant differences ($\alpha=0.05$) were found between species for all traits except IRS (Table 2). Year and species by year effects were significant for NP, NR, IRS, and RI ($\alpha=0.05$). The species were analysed individually to determine the effect of year, accession and accession by year on each of the four red rot criteria (Table 2). Significant effects were found for accession for all four traits; however, year was not always significant. For NP, no significant year effect was seen within *S. officinarum*, *S. sinense*, or the commercial cultivar, and for NR and IRS, year was insignificant for *S. barberi*, *S. spontaneum*, and the single commercial clone tested. RI showed no year effect for *S. barberi*, and LCP85-384. All accession by year effects were significant with the exception of NP for *S. robustum*. The ratio of variety F-values to interaction F-values was determined to assess the relative importance of variety by year interaction (Graybosch *et al*., 1996). For all traits and species analysed, the variety F-values were greater than the interaction, with the exception of NP, IRS, and RI for *S. sinense*. There were no common *Erianthus* clones in 2004 and 2008, so they were not included in the multi-year analysis. However, eight of the nine clones analysed across the three years showed complete or near complete resistance to red rot in all traits analysed.
Table 2—Summary of red rot scores for accessions included in multi-year analysis.

Species, number of nodes passed (NP), nodes rotted (NR), internode rot severity (IRS), and rot index\(^a\) (RI) are shown along with accession (A) and year (Y) mean separation and accession by year interaction (A*Y) analyses.

<table>
<thead>
<tr>
<th>Species</th>
<th>NP</th>
<th>NR</th>
<th>IRS</th>
<th>RI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial</td>
<td>7.8a</td>
<td>–</td>
<td>–</td>
<td>**</td>
</tr>
<tr>
<td>S. officinarum</td>
<td>6.3a</td>
<td>**</td>
<td>NS</td>
<td>**</td>
</tr>
<tr>
<td>S. sinense</td>
<td>4.7cd</td>
<td>*</td>
<td>NS</td>
<td>**</td>
</tr>
<tr>
<td>S. barberi</td>
<td>4.3d</td>
<td>**</td>
<td>NS</td>
<td>**</td>
</tr>
<tr>
<td>S. robustum</td>
<td>5.1bc</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>S. spontaneum</td>
<td>5.5b</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
</tbody>
</table>

*indicates significance at the \(\alpha=0.05\) level** indicates significance at the \(\alpha=0.01\) level. NS=nonsignificant. \(^a\)RI was calculated as RI = (NP + NR) \times \log_{10} (IRS+1).

A previous study conducted by Yin et al. (1994) showed that RI had the highest heritability of the four traits measured. This trait aims to combine different susceptibility traits of the disease to obtain an overall assessment of damage to both the stalk and the buds. RI scores less than five were highly resistant (showing minimal stalk and bud rot), while those less than 10 were moderately resistant. Variation was observed for RI within each of the Saccharum species (Figure 1). The highest level of variation was observed within S. spontaneum with RI means ranging from 2 to 29. Three of 31 accessions (10%) had an RI mean less than 5, and eight (26%) had a mean less than 10. The percentages of S. spontaneum clones with resistant and moderately resistant ratings in the Indian studies were 37 and 65% (Srinivasan and Alexander, 1971) and 35 and 71% (Satyavir et al., 1994), respectively. While less variation was observed among the S. barberi, a higher percentage of resistance was found within this species than was found within the others. Rot index ranged from one to 20 within S. barberi. Four of 14 accessions (29%) had a RI mean of less than 5, and six (43%) had a mean of 10 or less. The resistant and moderately resistant rating frequencies found in India for this species were 33 and 48% (Srinivasan and Alexander, 1971) and 6 and 22% (Satyavir et al., 1994), respectively.

When considering clones for disease resistance breeding, not only is the trait mean important, but also the variation within each species and the ease with which genes can be introgressed into commercial varieties. Erianthus clones showed the most consistent and most complete resistance to red rot. This suggests Erianthus could make an important contribution to an effort to enhance resistance in sugarcane. This is in agreement with a study conducted by Ram et al. (2001) who found that twelve out of 18 Erianthus clones tested showed resistance to red rot. However, it is not the only source of resistance genes, and certainly not the easiest to cross with elite sugarcane cultivars.

A wide range of variation was seen in S. spontaneum. While the overall average resistance of evaluated clones in this species was not as high as was demonstrated in India, there were still many clones that could be exploited for potential sources of resistance. S. spontaneum clones are more easily crossed with commercial sugarcane than Erianthus and produce more seed. Therefore, they are arguably the better candidates to utilise as more readily and rapidly exploitable sources of red rot resistance. Limited numbers of clones of the other Saccharum species were analysed, but the results indicate that, as a whole, S. barberi clones had a high level of resistance and could be easily exploited. S. barberi also had the highest ratio of variety to interaction F-values, indicating that, as a whole, this species is more stable across years and another good candidate for source genes for red rot resistance. The 3-year analysis results ranking suggested S. robustum might provide a source of resistance, but highly resistant clones were not detected in the species. Individual clones of S.
S. sinense, S. robustum, and S. officinarum might be identified that could serve as potential sources of resistance. However, individual clone resistance levels must be conclusively determined before using these Saccharum species in breeding due to variation among clones.

The significant interaction between year and accession for all species calls into question the ability to breed for resistance to red rot. However, this does not necessarily contradict successful breeding for the trait. As is observed with many screening studies, even with a significant interaction term, clones can be identified that have stable resistance across years. For example, in our multi-year analysis, we included 31 S. spontaneum accessions, and while statistical significance was found for the interaction between accessions and year, four clones were among the top 10 for resistance in both 2004 and 2008. This indicates that, with careful selection, enhanced resistance can be achieved through breeding. S. spontaneum clones identified as possessing red rot resistance in our study include but are not limited to: IND81-144, Guangxi 87-22, SES147B, and IN84-42. Of the S. barberi clones analysed, Dhalula and Ganapathy showed stable resistance. It does not appear necessary to heavily screen Erianthus clones for parental selection since most appear to possess near complete resistance to red rot. Furthermore, resistance to red rot in Erianthus makes it more attractive when considering the genus as a source of genes for other traits, such as low temperature tolerance. Transmitting an unfavourable trait, such as susceptibility to red rot, will not be a problem while introgressing the other traits of interest in this genus.

![Fig. 1—Variation in rot index (RI) between and within five Saccharum species in comparison to the susceptible commercial sugarcane variety LCP 85-384. Sources of genetic resistance to sugarcane red rot can be found among the Saccharum species, particularly S. spontaneum and S. barberi.](image-url)
Acknowledgments

The authors thank Cory Landry, Jennifer Shaw, Jeri Maggio, Katherine Warnke, Freddy Garces, Wilmer Barrera, and Carolyn Savario for their assistance in collecting stalks, inoculating with *C. falcatus*, splitting the stalks, and collecting the data.

REFERENCES


IDENTIFICATION DES SOURCES DE RÉSISTANCE À LA MORVE ROUGE DE LA CANNE À SUCRE

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MOTS CLÉS: Saccharum, Colletotrichum falcatum, Glomerella.

Résumé
LA MORVE ROUGE, causée par Colletotrichum falcatum Went, affecte de manière négative la plantation de la canne à sucre en Louisiane en provoquant une pourriture des boutures. Comme la résistance variétale est le moyen de lutte le plus efficace, une étude a été entreprise pour identifier les sources de résistance et évaluer leurs variabilités parmi les espèces de Saccharum et d’Erianthus. Les acquisitions clonales de Saccharum spontaneum, S. robustum, S. sinense, S. officinarum, S. barberi, et d’Erianthus ont été évaluées pour la résistance parallèlement aux cultivars commerciaux sensibles dans trois essais. Les tiges récoltées ont été inoculées au C. falcatum. Après six semaines d’incubation, chaque tige a été fendue et notée pour les symptômes de la morve rouge, en incluant le nombre de nœuds attaqués par la maladie (NP), le nombre de nœuds pourris (NR), la sévérité d’entreœufs attaqués (IRS), et l’index de pourriture (RI), qui tient compte de l’étendue des dégâts causés au nœud et à l’entreœuf. Des différences significatives ont été détectées parmi les espèces et les acquisitions inter-espèces pour tous les caractères. Parmi les espèces de Saccharum, S. barberi, S. robustum et S. spontaneum ont manifesté les moyennes de symptômes les moins sévères, alors que S. officinarum et S. sinense avaient les moyennes de sévérité les plus élevées. Un niveau élevé de variabilité a été observé parmi l’espèce S. spontaneum avec des moyennes de RI s’étalant de 2 à 29. Trois des 31 acquisitions de S. spontaneum (10%) avaient une moyenne de NR de moins que 5, et 26% avaient une moyenne de moins que 10. S. barberi a manifesté un niveau de résistance élevé, avec des moyennes RI s’étendant de un à 20. Quatre des 14 acquisitions de S. barberi (29%) avaient des moyennes RI de moins que 5 (très résistantes), et six (43%) avaient des moyennes de 10 ou moins (modérément résistantes). La variabilité la plus faible a été observée parmi les acquisitions d’Erianthus, toutes démontrant peu ou pas de symptômes de morve rouge. Le genre Erianthus possède donc une résistance élevée et devrait être utilisé comme parent dans les programmes d’hybridation génétique là où la résistance est requise. L’autre source de résistance à la morve rouge, plus facilement accessible, est le germoplasme de l’espèce Saccharum, dont certaines acquisitions de S. spontaneum et S. barberi.
IDENTIFICACIÓN DE FUENTES DE RESISTENCIA A LA PUDRICIÓN ROJA DE LA CAÑA DE AZÚCAR

Por

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PALABRAS CLAVES: Saccharum, Colletotrichum falcatus, Glomerella.

El muermo rojo o pudrición roja, causada por Colletotrichum falcatus Went, afecta negativamente el establecimiento de la caña de azúcar en Luisiana debido a la pudrición de los tallos sembrados. Debido a que la resistencia de los cultivares es el método de control más eficaz, se realizó un estudio para identificar las fuentes de resistencia a la pudrición roja y evaluar la variabilidad dentro de cada especie de Saccharum y Erianthus. Clones de accesiones de Saccharum spontaneum, S. robustum, S. sinense, S. officinarum, S. barberi y Erianthus se evaluaron en su resistencia a la enfermedad junto a cultivares comerciales susceptibles, en tres experimentos. Tallos cortados fueron inoculados con C. falcatus. Después de una incubación de 6 semanas, cada tallo se dividió longitudinalmente y calificaron los síntomas de la pudrición roja, incluyendo el número de nudos atravesados (NP), número de nudos podridos (NR), la severidad de la podredumbre del entrenudo (IRS), y un índice de pudrición (RI) que tiene en cuenta tanto la magnitud del daño de los nudos como la pudrición de los entrenudos. Se detectaron diferencias significativas entre las especies y las adhesiones dentro de las especies para todas las variables. Entre las especies de Saccharum, S. barberi, S. robustum y S. spontaneum exhibieron la menor severidad media de incidencia de la pudrición roja, mientras que S. officinarum y S. sinense exhibieron la mayor severidad media de incidencia de la enfermedad. Un alto nivel de variación se observó en S. spontaneum con RI que tuvo un rango de variación de 2 a 29. Tres de 31 accesiones de S. spontaneum (10%) tuvieron una media de NR inferior a 5, y 26% tenían una media de NR menor de 10. S. barberi mostró un alto nivel de resistencia, con medias de RI que variaron del uno al 20. Cuatro de 14 accesiones de S. barberi (29%) tuvieron una media de RI inferior a 5 (muy resistente), y seis (43%) tuvieron una media de RI de 10 o menos (moderadamente resistente). La menor variación en los resultados se observó entre las accesiones de Erianthus, con todas mostrando muy poco o ningún síntoma de pudrición roja. El género Erianthus posee una alta resistencia y debe ser utilizado como material progenitor en los programas de mejoramiento que requieran mejorar la resistencia a la pudrición roja. Otras fuentes de mayor facilidad en su utilización como fuentes de resistencia a la pudrición roja en el germoplasma de Saccharum, se pueden buscar en las accesiones de S. spontaneum y S. barberi.
UNRAVELLING PATHOGENICITY OF XANTHOMONAS ALBILINEANS, THE CAUSAL AGENT OF SUGARCANE LEAF SCALD

By

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KEYWORDS: Genome, Functional Genomic Analysis.

Abstract

Xanthomonas albilineans is a systemic, xylem-invading pathogen that causes leaf scald in sugarcane. Symptoms vary from a single, white, narrow, sharply defined stripe to complete wilting and necrosis of infected leaves, leading to plant death. X. albilineans produces the toxin, albicidin, that blocks chloroplast differentiation, resulting in disease symptoms. Albicidin is the only previously known pathogenicity factor in X. albilineans, yet albicidin-deficient mutant strains are still able to efficiently colonise sugarcane. The complete genome of strain X. albilineans GPE PC73 from Guadeloupe was recently sequenced and annotated, providing a valuable tool to help identify new pathogenicity factors in this pathogen. In attempts to identify additional pathogenicity genes, site-directed deletions of candidate pathogenicity genes and also random Tn5 insertion mutagenesis were used, both followed by inoculation of sugarcane plants with new strains containing introduced mutations. Knockout mutagenesis of albXXI, which encodes a phosphopantetheinyl transferase that activates non ribosomal peptide synthetases (NRPSs), resulted in reduced capacity to colonise the sugarcane stalk by GPE PC73. Knockout mutagenesis of quorum sensing genes, rpfF and xanB2, did not affect albicidin production nor sugarcane colonisation by X. albilineans strain XaFL07-1 from Florida. However, four independent Tn5 insertion mutations of an OmpA family gene strongly affected both disease symptom development and sugarcane stalk colonisation without affecting albicidin production in strain XaFL07-1. Other candidate pathogenicity genes are currently being investigated.

Introduction

Leaf scald, a vascular bacterial disease, is one of the major diseases of sugarcane (Rott and Davis, 2000). It was first recorded in Australia in 1911 by North, but strong presumptive evidence exists that the disease was prevalent in the Fiji Islands by 1908, if not earlier (Martin and Robinson, 1961). Today, the disease occurs in most sugarcane growing locations. Successful isolation of the causal agent, Xanthomonas albilineans, was reported in 1920 by Wilbrink who was also able to reproduce the symptoms of the disease after artificial inoculation (Wilbrink, 1920).

Although X. albilineans is thought to be mainly transmitted by infected cuttings, aerial transmission of this pathogen also occurs, and epiphytic life of the pathogen appears to be an important step in the epidemiological cycle of the disease (Autrey et al., 1995a; Champoiseau et al., 2009). Control of leaf scald is achieved by various methods including use of resistant cultivars and prophylactic measures (use of disease-free nursery material, disinfection of harvesting tools, etc.). Successful control based on resistance implies knowledge of genetic diversity and variation in pathogenicity of the pathogen. The objective of this paper is to review the literature on pathogenicity of X. albilineans and its genetic basis, and report recent research unravelling pathogenicity of this pathogen.
Leaf scald symptoms and colonisation of the sugarcane stalk

In the field, the symptoms of sugarcane leaf scald are sometimes classified into two different forms, chronic and acute (Martin and Robinson, 1961; Ricaud and Ryan, 1989). It is unknown if these two forms are caused by entirely different sets of genes in different strains of the pathogen, by gene regulation differences among similar strains, or by external, environmental factors that may act on identical strains. The chronic form is characterised by chlorotic streaks on leaves which are parallel to the main veins. These are generally white to yellow narrow ‘pencil-line’ streaks, but they can also be several millimetres wide. Their colour often becomes reddish with age. They are the only external symptoms which develop on resistant cultivars (Rott and Davis, 2000). As the disease progresses, a necrosis of the leaf tissue around the chlorotic streaks may be observed which extends progressively from the tip towards the base of the leaf. The streaks also tend to widen and become more diffuse on leaves reaching maturity. The fine central line which is characteristic of the disease can, however, always be seen in the centre of the lesion. The widening of the lines coincides with the chlorosis or the bleaching of the leaf tissue. Chlorosis or bleaching may affect all the leaves, and this discoloration is followed by a desiccation of leaf extremities which curl inwards, giving the shoot or the stalk a tapered aspect. The stalks can be stunted and the leaves wilted, brown, and bent at the ends. This process, which looks like a scalding, explains the name given to the disease.

A common symptom observed in the chronic form of leaf scald in mature cane arises from abnormal development of side shoots on stalks with basal side shoots generally being more developed than those higher up, in contrast to the opposite situation commonly observed in healthy stalks. These diseased side shoots may show similar symptoms to those on the main stalk. Longitudinal sections of diseased stalks show reddening of the vessels near the nodes and sometimes in the internodes. Lysigenous cavities may be observed in severely diseased canes. The whole stalk may die in susceptible cultivars.

The acute form of leaf scald disease is characterised by a sudden wilting of mature stalks, often without previous development of symptoms associated with the chronic form. Previously symptomless sugarcane dies as if it had been killed by drought. This acute form often occurs after a period of rain followed by a period of prolonged dry weather, but seems to be limited to highly susceptible cultivars.

Another important feature of leaf scald is the existence of a latency phase (Martin and Robinson, 1961; Ricaud and Ryan, 1989). Sugarcane plants can be infected by X. albilineans for weeks or months without exhibiting symptoms or symptoms are so inconspicuous as to escape detection. This latency phase comes to an end for unknown reasons, and symptoms of the chronic or acute forms of leaf scald disease will then appear.

Regardless of the disease form observed, X. albilineans multiplies in the xylem and systemically colonises the entire host plant: the leaves, the stalk and the roots (Champoiseau et al., 2006b; Klett and Rott, 1994). The pathogen can be easily isolated from pencil line symptoms but rarely from chlorotic parenchymatic tissue (Birch, 2001). Pathogen population densities vary according to the sugarcane cultivar and the plant location, and resistance of sugarcane is linked to limited colonisation of the sugarcane stalk (Rott et al., 1997).

Genetic basis of albicidin biosynthesis and structure of albicidin

Birch and Patil first showed in 1985 that a potent phytotoxin and antibiotic was produced by X. albilineans (Birch and Patil, 1985a and 1985b). Albicidin is a small molecule synthesised by a unique, large, and mixed PKS (polyketide synthase)-NRPS (non ribosomal peptide synthetase) gene cluster. Albicidin has been shown to cause leaf scald foliar symptoms in sugarcane by inhibiting the replication of proplastic DNA and consequently blocking the differentiation of chloroplasts (Birch and Patil, 1987a and 1987b). On a molecular level, it has been found to be a potent and novel DNA gyrase inhibitor (Hashimi et al., 2007). The albicidin biosynthesis gene cluster was cloned and
 sequenced (Rott et al., 1996; Royer et al., 2004). It contains 20 ORFs including one PKS-NRPS gene (\textit{albI}) and two NRPS genes (\textit{albIX} and \textit{albIV}), as well as several putative resistance, regulatory and modifying genes (Figure 1). \textit{In silico} analyses showed that nonproteinogenic substrates incorporated by AlbI and AlbIX are unique and remain unknown (Royer et al., 2004). Two other genes located in other parts of the genome are also critical for the biosynthesis of albicidin: \textit{albXXI} which encodes a phosphopantetheinyl transferase (Royer et al., 2004) and \textit{albXXII} which encodes the heat-shock protein HtpG (Vivien et al., 2005).

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{physical_map.png}
\caption{Physical map of the albicidin biosynthesis gene cluster.}
\end{figure}

Preliminary analyses by NMR (Nuclear Magnetic Resonance) spectroscopy and mass spectrometry (MS) performed in the 1980s with purified albicidin did not result in the determination of the complex structure of albicidin (Birch and Patil, 1985a and 1985b). However, these structural analyses showed that albicidin has about 38 carbon atoms and an estimated molecular mass of 842 Da. According to these reports, the albicidin structure contains a methyl group, a carboxyl group and at least three aromatic rings (Birch and Patil, 1985a and 1985b).

\textit{X. albilineans} is a slow growing bacterium and production yields of albicidin are low; it was extremely tedious to obtain sufficient amounts of albicidin for structure elucidation. To overcome this problem, Vivien et al. (2007) used heterologous expression by transferring all albicidin biosynthesis genes into the fast growing bacterium \textit{X. axonopus pv. vesicatoria} and obtained a significant increase of albicidin production. Even larger quantities of purified albicidin have more recently been obtained (Cociancich et al., 2007 and 2009), which may allow elucidation of the structure of albicidin.

\section*{Variation in pathogenicity and genetic diversity of \textit{Xanthomonas albilineans}}

Breakdown of varietal resistance to leaf scald has sometimes been attributed to the development or introduction of new strains but has never been unequivocally proven. Variation in pathogenicity among strains of \textit{X. albilineans} is known to occur, and published data support the possible existence of different races in Mauritius (Autrey et al., 1995b). The outbreak of leaf scald in Florida in the late 1980s was closely associated with the appearance of a genetically new strain of the pathogen (Davis et al., 1997). The capacity of \textit{X. albilineans} to colonise sugarcane stalks and/or to cause symptoms varies according to the strain of the pathogen, indicating the existence of different pathotypes within the species (Champoiseau et al., 2006a; Daugrois et al., 2003; Huerta-Lara et al., 2009; Mohamed et al., 1996).

First evidence of genetic diversity of \textit{X. albilineans} was described by Rott and collaborators who reported the existence of three serovars and six lysovars of the pathogen (Rott et al., 1986 and...
1994). Subsequently, existence of different genetic profiles or genetic variation in *X. albilineans* was reported by several authors using various techniques, but the correlation between genetic diversity and variation in pathogenicity was rarely investigated (Alvarez et al., 1996; Huerta-Lara et al., 2009; Jaufeerally-Fakim et al., 2002; Lopez et al., 2001; Shaik et al., 2008; Yang et al., 1993). Existence of at least eight genetic groups (A-H) were identified by restriction fragment length polymorphism with pulse-field gel electrophoresis (RFLP-PFGE), and most strains associated with new outbreaks of leaf scald belonged to PFGE group B (Davis et al., 1997). Fourteen haplotypes and two major genetic groups (ALB-RFLP A and ALB-RFLP B) were identified among 137 worldwide strains of *X. albilineans* using DNA probes harbouring the albicidin biosynthetic genes (Champoiseau et al., 2006a).

Not surprisingly, albicidin production *in vitro* varies according to the strain of *X. albilineans*. However, variation in albicidin production and variation in pathogenicity are not necessarily related to the diversity of albicidin biosynthesis genes. High variation in pathogenicity was shown to exist in genetically closely related strains of *X. albilineans* in Guadeloupe (Champoiseau et al., 2006b) and no relationship was found either among the amount of albicidin produced *in vitro* and the pathotypes and genetic diversity of the pathogen (Renier et al., 2007). Albicidin is therefore necessary but not sufficient for leaf scald development, and it appears to be one virulence factor acting coordinately with other virulence factors.

**The genome of *Xanthomonas albilineans* and pathogenicity**

The complete genome of *X. albilineans* strain GPE PC73 from Guadeloupe has been recently sequenced and annotated (Pieretti et al., 2009). This work revealed that the size of this genome (3.7 Mb) was relatively small in comparison to the size of the genomes of other xanthomonads sequenced to date (approximately 5 Mb). Interestingly, *X. albilineans* possesses 522 genes that are not conserved in other sequenced species of the *Xanthomonadaceae* family, and is missing the hypersensitive response and pathogenicity (Hrp) secretion system. This type III secretion system (T3SS) is found in most other pathogenic xanthomonads and is used for injection of protein pathogenicity effectors into plant cells. *X. albilineans* also lacks all genes involved in biosynthesis of xanthan gum which are involved in formation of biofilm, an important factor in virulence of plant pathogenic bacteria.

The remarkable absence of a type III secretion system of the Hrp injectisome family in the genome of *X. albilineans* implies that pathogenicity of *X. albilineans* relies on other secretion systems. Small molecules, such as albicidin, which require only pumps to be secreted by the bacterium and to enter the plant cell, may play an important role in pathogenicity of this pathogen.

This assumption is based on findings that the genome of *Xa* contains 12 NRPS genes clustered in four genomic regions potentially involved in the biosynthesis of four small molecules. These 12 NRPS genes are very different from those described in other microorganisms, and cover almost 4% of the bacterial genome.

Three of these 12 NRPS genes were previously described as required for the biosynthesis of albicidin (Royer et al., 2004).

**Identification of new pathogenicity genes of *X. albilineans***

If albicidin is a major factor in symptom development, it is not the only one involved in disease progress. Mutants of *X. albilineans* that do not produce the toxin are still able to colonise the sugarcane leaf and stalk (Birch, 2001; Marguerettaz et al., unpublished results). Therefore, several studies have recently been started to identify new pathogenicity genes in *X. albilineans*.

**Quorum sensing genes**

The genome sequence of *X. albilineans* revealed candidate genes potentially involved in pathogenesis. These candidates include a cluster of genes called rpf (regulation of pathogenicity...
factors) involved in the biosynthesis of a small diffusible signalling molecule. This molecule called DSF (Diffusable Signalling Factor) is synthesised by RpfF which exhibits similarities to long-chain fatty acyl CoA ligases (Barber et al., 1997; Dow 2008). DSF mediates cell-to-cell signalling (= quorum sensing) and disruption of genes rpfF or rpfC (a hybrid two-component DSF sensor) resulted in reduced or deficient virulence in different xanthomonads, such as X. campestris pv. campestris, X. oryzae pv. oryzae and X. axonopodis pv. citri (Chatterjee et al., 2008; Dow, 2008). However, mutants of rpfF and rpfC in X. albilineans strain XaFL07-1 from Florida were still able to produce albicidin, to colonise the sugarcane stalk and to induce leaf scald symptoms including ‘pencil-line’ streaks, chlorosis and necrosis of leaves (Rott et al., 2009b). DSF is therefore not essential for albicidin production or sugarcane colonisation by X. albilineans.

Xanthomonas species also produce another quorum sensing molecule called DF (Diffusable Factor) encoded by xanB2 (previously called pigB). In X. campestris pv. campestris, DF regulates the production of both yellow pigments (xanthomonadins) and extracellular polysaccharide (EPS), and these two bacterial products are crucial to the epiphytic survival and pathogenicity of the pathogen on its host plants (Poplawsky and Chun, 1997 and 1998). However, mutants of xanB2 in X. albilineans strain XaFL07-1 from Florida were still able to produce albicidin, to colonise the sugarcane stalk and to induce leaf scald symptoms including ‘pencil-line’ streaks, chlorosis and necrosis of leaves (Rott et al., 2009a). DF is therefore not essential for albicidin production or sugarcane colonisation by X. albilineans, and these two characteristics may not be controlled by quorum sensing or may involve another regulatory pathway. However, it is possible that DF, like in X. campestris pv. campestris, is crucial to the epiphytic survival of X. albilineans during aerial transmission of the leaf scald pathogen.

NRPS genes

Other genes putatively involved in pathogenicity of X. albilineans include NRPS genes that are involved in the biosynthesis of small molecules. As mentioned above, the genome of X. albilineans encodes 12 large non-homologous non-ribosomal peptide synthetases (NRPSs). Three of these NRPSs, encoded in the same gene cluster, were previously described as involved in albicidin biosynthesis (Royer et al., 2004). The function of the remaining nine NRPSs is currently unknown but it has been hypothesised that they may be involved in biosynthesis of small molecules playing a role in sugarcane-X. albilineans interactions. NRPS enzymes need posttranslational activation by a phosphopantetheinyl transferase enzyme in order to be functional (Lambalot et al., 1996). The genome of X. albilineans strain GPE PC73 contains the gene albXXI which encodes a phosphopantetheinyl transferase and which was previously shown to be required for albicidin biosynthesis (Huang et al. 2000; Royer et al., 2004). This gene may therefore be used for post-translational activation of all NRPSs encoded by X. albilineans. Inactivation of albXXI in X. albilineans strain GPE PC73 resulted in suppression of leaf scald symptoms and reduced capacity to colonise the sugarcane stem when compared to the wild type strain (Marguerettaz et al., 2009). This suggested that at least two secondary metabolites synthesised by NRPSs are involved in virulence of X. albilineans strain GPE PC73: (i) albicidin, which causes the white pencil line streaks on the leaves, and (ii) at least another molecule necessary for stalk colonisation.

Outer membrane protein A gene

Tn5 (transposome) mutagenesis was also used in an attempt to identify additional pathogenicity factors in X. albilineans. Sugarcane cultivar CP80-1743, moderately susceptible to leaf scald, was inoculated by the decapitation method (Champoiseau et al., 2006a) with 780 independently derived Tn5 insertions in Florida strain XaFL07-1. Leaf scald symptoms were recorded on emerging leaves one month after inoculation, and stalk colonisation by the pathogen was determined two months after inoculation. In addition to the previously identified albicidin biosynthetic gene cluster mutations, four new Tn5 mutants were identified that produced no or very
few leaf symptoms. These mutants produced albicidin \textit{in vitro} but did not efficiently colonise sugarcane stalks. The transposon insertion site of all four mutants was found to be located in Orf XAAlc_0557 of the \textit{X. albilineans} genome. This gene is predicted to encode an OmpA family outer membrane protein, a previously unrecognised and apparently essential pathogenicity factor in \textit{X. albilineans} (Rott \textit{et al}., 2009a).

Other genes

Additional Tn$\text{5}$ mutants affected in symptom development or in sugarcane stalk colonisation have been obtained, such as mutants affecting production of exopolysaccharides (EPS) and lipopolysaccharides (LPS) (Rott \textit{et al}., unpublished data). These mutants will be further investigated and more mutants will also be tested by sugarcane inoculation to identify additional pathogenicity genes in \textit{X. albilineans}.

Conclusion

The xylem-invading mechanisms of plant pathogenic bacteria are still not well characterised. The \textit{X. albilineans}/sugarcane pathosystem is an original model in plant pathology to study xylem-invading pathogens, and certain aspects of its invasive ability may be unique.

First, \textit{X. albilineans} is constrained within the xylem, but disease symptoms result from changes in chlorenchyma cells; nevertheless, the bacteria are rarely found in chlorotic leaf areas.

Second, \textit{X. albilineans} infections can be latent for many weeks or months before occurrence of acute disease, and this latency phase ends for unknown reasons. It is thought that this phase change is most likely regulated by particular pathogenicity genes of the pathogen.

Third, \textit{X. albilineans} does not possess a Hrp secretion system. Finally, \textit{X. albilineans} produces albicidin, a unique and specific toxin that causes foliar leaf scald symptoms.

Extensive research has been conducted on \textit{X. albilineans} since its first description more than a century ago. Important knowledge regarding the biology of this pathogen has been gained, and genetic diversity studies and pathogenicity studies showed that this pathogen is variable and evolving. However, more studies are needed to understand the \textit{X. albilineans}/sugarcane pathosystem, especially the interactions between the host and the pathogen.

Recent description of the genome of \textit{X. albilineans} will certainly result in new and significant progress, especially regarding the molecular basis of pathogenicity of this pathogen and its interactions with sugarcane.

First genes involved in pathogenicity, such as genes involved in albicidin biosynthesis and in an outer membrane protein have been identified, and more will certainly follow in the near future. Several mutagenesis techniques are already used to identify new candidate genes potentially involved in pathogenesis.

Other methods such as microarray technology will also be used to investigate the full breadth of the response of \textit{X. albilineans} to the sugarcane host environment during colonisation of the xylem, and maybe also during the epiphytic life of the pathogen.

Acknowledgments

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REFERENCES


**DECRYPTAGE DE LA PATHOGENIE DE XANTHOMONAS ALBILINEANS, L’AGENT CAUSAL DE L’ECHAUDURE DES FEUILLES DE LA CANNE A SUCRE**

Par

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**MOTS CLES: Génome, Analyse Génomique Fonctionnelle.**

**Résumé**

*Xanthomonas albilineans* est un agent pathogène colonisant le xylème et l’agent causal de l’échaudure des feuilles de la canne à sucre. Les symptômes varient d’une très fine ligne foliaire blanche à un flétrissement complet et la nécrose des feuilles infectées, conduisant à la mort de la plante. *X. albilineans* produit la toxine albicidine qui bloque la différenciation des chloroplastes, ce qui aboutit à l’apparition de symptômes foliaires. L’albicidine était le seul facteur de pathogénie connu jusqu’à récemment, même si des souches non productrices d’albicidine étaient toujours capables de coloniser la canne à sucre. Le génome complet de la souche de *X. albilineans* GPE PC73 originale de Guadeloupe a récemment été séquencé et annoté, fournissant ainsi un outil fort utile à l’identification de nouveaux facteurs de pathogénie chez cet agent pathogène. Afin d’identifier de nouveaux gènes de pathogénie, des mutants de délétion dirigée et d’insertion aléatoire (Tn5) ont été produits puis inoculés à des plants de canne à sucre. La mutation du gène *albXXI*, qui code pour une phosphopantetheinyln transférase activant les enzymes NRPS («Non Ribosomal Peptide Synthetases»), a réduit la capacité colonisatrice de la tige de canne à sucre chez la souche GPE PC73 de *X. albilineans*. La délétion par mutagenèse dirigée des gènes de signalisation cellulaire *rpfF* et *xanB2* n’a apparemment pas eu d’effet sur la production d’albicidine ou la colonisation de la tige de canne à sucre par la souche de *X. albilineans* XaFL07-1 originaire de Floride. Cependant, quatre mutations Tn5 indépendantes d’un gène de la famille OmpA a fortement affecté le développement de symptômes et la colonisation de la tige, sans modifier la production d’albicidine, chez la souche XaFL07-1 de *X. albilineans*. D’autres gènes candidats de pathogénie sont actuellement à l’étude.
VARIACIONES EN LA PATOGENICIDAD DE XANTHOMONAS ALBILINEANS, EL AGENTE CAUSAL DE LA ESCALDADURA DE LA HOJA DE LA CAÑA DE AZÚCAR

Por

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PALABRAS CLAVES: Genoma, Análisis Genómico Functional.

Resumen

XANTHOMONAS albilineans es un patógeno sistémico, que invade el xilema y causa la escaldadura de la hoja de la caña de azúcar. Los síntomas pueden variar desde la aparición de una sola raya blanca, angosta, bien definida hasta tener una completa marchitez y necrosis de las hojas afectadas, lo que lleva a la muerte de la planta. Además, X. albilineans produce la toxina, albicidina, que bloquea la diferenciación de cloroplastos, lo que resulta en la aparición de los síntomas de la enfermedad. La albicidina ha sido conocida como el único factor de patogenicidad asociado con X. albilineans, y es así como cepas mutantes con deficiencia en la producción de la albicidina, son capaces de colonizar de manera eficiente la caña de azúcar. El genoma completo de la cepa X. albilineans GPE PC73 proveniente de Guadalupe se secuenció recientemente, proporcionando así una herramienta muy valiosa en la identificación de nuevos factores de patogenicidad de este agente causal. En un intento por identificar los genes patogénicos adicionales, se produjeron supresiones de genes candidatos así como inserciones al azar por mutagénesis de Tn5, seguidos por la inoculación de plantas de caña de azúcar con las nuevas cepas que contienen las mutaciones introducidas. El bloqueo por mutagénesis de albXXI, que codifica la transferasa fosfopantetienil y que activa los péptidos sintetasas no ribosomales (NRPSs), produjo una reducción en la capacidad de la cepa GPE PC73 de colonizar el tallo de la caña de azúcar. El bloqueo por mutagénesis de genes quorum sensing, rpfF y xanB2, de X. albilineans cepa XaFL07-1 de Florida no afectaron la producción de la albicidina ni la colonización de la caña de azúcar. Sin embargo, cuatro mutantes por inserción independiente del gen Tn5 de la familia Ompa, en la cepa XaFL07-1, fueron afectados fuertemente tanto en el desarrollo de los síntomas de la enfermedad como en la colonización de tallos de la caña de azúcar sin afectar la producción de la albicidina. Otros genes de patogenicidad están siendo investigados.
GENETIC DIVERSITY OF SUGARCANE YELLOW LEAF VIRUS IN A SUGARCANE SELECTION PLOT IN GUADELOUPE (FWI)

By

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KEYWORDS: SCYLV, Genetic Diversity.

Abstract

The genetic diversity of Sugarcane yellow leaf virus (SCYLV) was investigated in a sugarcane selection plot in Guadeloupe to determine the incidence of the different known virus genotypes (BRA-PER, CUB and REU) in a breeding progeny. Four F1 leaves were randomly collected from each of 154 sugarcane clones and tested for the presence of SCYLV by tissue blot immunoassay (TBIA). The leaf samples were stored at –80°C until total RNA was extracted from SCYLV-infected leaves. The virus genotypes were determined by RT-PCR and primer pairs specific to each virus genotype. Eighty-two percent of the tested leaves were infected by SCYLV and all known virus genotypes occurred in the selection plot. The majority of plants were infected by genotypes CUB or REU, or by a mixture of these two genotypes. This situation was completely different from the situation observed in commercial fields in Guadeloupe where the incidence of SCYLV is much lower and where most plants are infected by genotype REU. The significance of this striking situation will be further investigated.

Introduction

Yellow leaf of sugarcane is an emerging disease that was first reported as yellow leaf syndrome in Hawaii and Brazil at the end of the 1980s (Rott et al., 2008). It was subsequently found to be associated with a member of the Luteoviridae family called Sugarcane yellow leaf virus or SCYLV that was assigned to the genus Polerovirus (Rott et al., 2008; D’Arcy and Domier, 2005).

Sequencing of the almost entire genome of 13 SCYLV isolates revealed that SCYLV was genetically heterogeneous, and four genotypes of the virus were identified: BRA for Brazil, CUB for Cuba, PER for Peru, and REU for Réunion Island. Genotypes BRA and PER, that are closely related, cannot be easily distinguished, and were assigned to a group of genotypes called ‘BRA-PER’ (Abu Ahmad et al., 2006a).

This latter genotype is widely distributed, whereas the other ones are geographically restricted (Abu Ahmad et al., 2006b). Recently, a new genotype named IND was reported in India (Viswanathan et al., 2008).

Because (i) infected plants are frequently symptomless, and (ii) efficient diagnostic methods were only available by the end of the 1990s, SCYLV was spread all over the world through infected germplasm. So far, the virus has been reported in at least 30 countries (Rott et al., 2008).
Consequently, many of the sugarcane clones that are imported into CIRAD’s sugarcane quarantine in Montpellier (France) are infected with SCYLV, and have to be cleaned up from the virus before distributing to other countries (Chatenet et al., 2001; Girard et al., 2007). During the process of SCYLV detection in CIRAD’s quarantine, we recently noticed that a high proportion of SCYLV-infected clones received from CIRAD’s sugarcane breeding station in Guadeloupe (FWI) were infected by genotype CUB. This situation was unexpected because other data from Guadeloupe indicated that REU was the most common genotype on this island (Daugrois et al., 2008).

Leaf samples were therefore collected in the sugarcane selection plot used to distribute sugarcane clones from Guadeloupe to the sugarcane quarantine in Montpellier. These samples were tested to analyse the incidence and the genetic diversity of SCYLV in this selection plot, and to compare this genetic diversity to the one occurring in commercial fields in Guadeloupe.

Materials and methods

**Selection of leaf samples**

Four F1 (= top visible dewlap) leaves were randomly sampled from each of 154 sugarcane clones planted in a selection plot at CIRAD’s research station in Guadeloupe (FWI). These clones were progenies of 14 crosses and they were at third selection stage of a family selection. After tissue blot immunoassay (see below), the leaves were stored at –80°C until further processing. RT-PCR detection and genotyping tests were performed with two successive sets of leaf samples: in the first step, 38 out of the 154 sugarcane clones were randomly selected among the clones, and two leaves per clone were individually analysed. This sample selection will be thereafter called set A. Later on, 18 sugarcane clones were selected for additional analyses among clones that tested either positive or negative by TBIA using all four sampled leaves. This sample selection will be called set B. Each leaf of set B was individually tested by RT-PCR.

**Virus detection by tissue blot immunoassay**

Tissue blot immunoassay (TBIA) was performed as described by Schenck et al. (1997), except that nitrocellulose membranes and Fast Blue salt (Sigma®) were used. TBIA membranes were analysed with a stereomicroscope (x10) to determine positive reactions.

**Virus detection and genotyping by RT-PCR**

**RNA extraction**

One hundred mg of each selected leaf sample was used for RNA extraction with QIAGEN® RNeasy Plant Mini Kit (Qiagen, Valencia, CA) following the manufacturer’s protocol. Total RNA was eluted in DEPC RNase-free water and stored at –20°C for future use.

**RT-PCR test with generic primers**

A specific SCYLV genome fragment from the coat protein coding region was amplified by RT-PCR using primers ScYLVf1 (GACAGACTCGGCCAGTGGTCGTG) and ScYLVr1 (GTAAGCCATTGTTGAACGCTGCG). The RT-PCR reaction was performed using QIAGEN® OneStep RT-PCR Kit.

The 25 µL RT-PCR reaction mix consisted of 1 µL of eluted RNA, 17.05 µL of RNase-free water, 5 µL of RT-PCR buffer (5X), 0.5 µL of dNTP mix (10 mM), 0.10 µL of each primer (100 µM), 1 µL of RT-PCR mix and 0.25 µL of RNase inhibitor (Invitrogen, Carlsbad, CA). The RT-PCR program was as follows: 50°C for 30 min, 95°C for 5 min, 30 cycles at 94°C for 1 min, 71°C for 1 min and 72°C for 30 sec with a final 72°C extension for 10 min. The PCR product was analysed by electrophoresis through a 1.0% agarose gel in TAE buffer, stained with ethidium bromide and visualised under UV light. The SCYLV amplification product had an expected size of 219 bp.
**Virus genotyping**

Only samples that tested positive with SCYLV generic primers were used to identify the SCYLV genotype(s) by RT-PCR with genotype specific primers. The amplification of a specific genome fragment from each SCYLV genotype was performed as described by Ahmad et al. (2006b), except that QIAGEN® OneStep RT-PCR Kit was used. The 25 µL RT-PCR reaction mix consisted of 1 µL of eluted RNA, 12.05 µL of RNAse-free water, 5 µL of Q solution, 5 µL of RT-PCR buffer (5X), 0.5 µL of dNTP mix (10 mM), 0.10 µL of each primer (100 µM), 1 µL of RT-PCR mix and 0.25 µL of RNAse inhibitor (Invitrogen ref.10777-019).

The RT-PCR program was as follows: 50°C for 30 min, 95°C for 5 min, 30 cycles at 94°C for 1 min, 56°C for 1 min and 72°C for 1 min with a final 72°C extension for 10 min. The PCR products were analysed by electrophoresis through a 1% agarose gel in TAE buffer, stained with ethidium bromide and visualised under UV light. The SCYLV amplification products of SCYLV genotypes BRA-PER, CUB and REU had expected sizes of 362, 450, and 905 bp, respectively.

**Statistical analyses**

All statistical analyses were made using SAS software v.9.1. Frequency comparisons between different sugarcane populations of RT-PCR positive and negative samples as detected with generic primers were made using Fisher’s exact test under freq procedure. Frequency comparisons of virus genotypes between the same sugarcane populations were made among RT-PCR positive samples as detected with generic primers using Fisher's exact test.

Comparisons of virus genotype frequencies within set A and set B pooled data were made under GLM procedure after arcsin transformation of genotype proportions.

**Results**

**SCYLV detection by TBIA**

Five hundred and twenty out of 632 sampled leaves (82%) tested SCYLV positive by TBIA. Additionally, at least one virus-infected leaf was found for 143 out of 154 sugarcane clones (93%). The virus was not detected in 112 plants (18%) and 11 sugarcane clones (7%).

**Detection by RT-PCR**

Among the 76 leaves of set A (38 sugarcane clones), 65 were positive for SCYLV by RT-PCR. Five leaves that tested negative by TBIA were positive by RT-PCR, and seven leaves that tested positive by TBIA were negative by RT-PCR. Fifty five of 61 leaves of set B were SCYLV-positive by RT-PCR, and eight leaves that were TBIA negative tested positive by RT-PCR. Frequencies of RT-PCR positive leaves were not different between set A and set B (P = 0.44, Fisher’s exact test).

**Genotyping**

The three SCYLV genotypes (BRA-PER, CUB and REU) were found in sets A and B, and the observed genotype incidences are detailed in Table1. Because incidences of genotypes BRA-PER, CUB and REU were not different between sample sets A and B, the data from both sets were pooled for further analyses. Virus genotype CUB had the highest incidence, followed by genotype REU and genotype BRA-PER (Table 2).

Most samples were infected by a single virus genotype (47.4%), but patterns of co-infection combining two or three genotypes were also found. Seventeen (12.4%) of the leaves were RT-PCR negative, 8 leaves (5.8%) were infected by BRA-PER only, 16 leaves (11.7%) by REU only, and 41 leaves (29.9%) by CUB only.

Five leaves (3.6%) were infected simultaneously by BRA-PER and REU, 10 leaves (7.3%) by BRA-PER and CUB, and 36 leaves (26.3%) by CUB and REU. Four leaves (2.9%) contained all three virus genotypes.
Table 1—SCYLV genotype incidences in two sets of leaf samples collected in a stage 3 breeding plot.

<table>
<thead>
<tr>
<th>RT-PCR primers</th>
<th>Test result</th>
<th>Number of leaves in sample set A</th>
<th>Number of leaves in sample set B</th>
<th>P = (Fisher’s exact test)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCYLV generic primers</td>
<td>+</td>
<td>65</td>
<td>55</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>11</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>CUB specific primers</td>
<td>+</td>
<td>51</td>
<td>40</td>
<td>0.52</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>14</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>REU specific primers</td>
<td>+</td>
<td>30</td>
<td>31</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>35</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>BRA-PER specific primers</td>
<td>+</td>
<td>18</td>
<td>9</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>47</td>
<td>46</td>
<td></td>
</tr>
</tbody>
</table>

Table 2—Comparison of SCYLV genotype incidences in a stage 3 breeding plot.

<table>
<thead>
<tr>
<th>SCYLV genotype</th>
<th>% of virus-infected leaves</th>
<th>Homology groups (student’s test)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUB</td>
<td>66.4</td>
<td>a</td>
</tr>
<tr>
<td>REU</td>
<td>44.5</td>
<td>b</td>
</tr>
<tr>
<td>BRA-PER</td>
<td>19.7</td>
<td>c</td>
</tr>
</tbody>
</table>

Interaction between plant characteristics and virus genotype incidences

The plant genetic background (i.e. crosses) and the characteristics of TBIA positive clones were studied taking into account virus genotype incidences.

The progenies of two crosses (#28 and #160) represented by more than 20 leaf samples were chosen and compared together, but also to the other remaining sampled crosses (Table 3).

RT-PCR positive sample frequencies of these three plant genetic groups varied from 75% to 95%. The plant genetic background had a significant effect on RT-PCR positive leaf frequency (P = 0.037) and also a strong effect on CUB and REU incidences, but not on BRA-PER incidence (Table 3).

Virus genotype incidences between the three groups of clones varied from 56% to 98%, 33% to 71% and 13% to 30% for CUB, REU and BRA-PER, respectively.

Table 3—SCYLV genotype incidences in 3 different plant genetic backgrounds of samples collected in a stage 3 breeding plot.

<table>
<thead>
<tr>
<th>RT-PCR primers</th>
<th>RT-PCR test result</th>
<th>Cross 28 B85342xCP76-331</th>
<th>Cross 160 B7784xD172</th>
<th>Other crosses</th>
<th>P = (Fisher’s exact test)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCYLV generic primers</td>
<td>+</td>
<td>21</td>
<td>42</td>
<td>57</td>
<td>0.037</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>7</td>
<td>2</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>CUB specific primers</td>
<td>+</td>
<td>18</td>
<td>41</td>
<td>32</td>
<td>1.65 × 10⁻⁶</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>3</td>
<td>1</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>REU specific primers</td>
<td>+</td>
<td>7</td>
<td>30</td>
<td>24</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>14</td>
<td>12</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>BRA-PER specific primers</td>
<td>+</td>
<td>5</td>
<td>5</td>
<td>17</td>
<td>0.107</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>16</td>
<td>37</td>
<td>40</td>
<td></td>
</tr>
</tbody>
</table>
The sugarcane clones were distributed into two groups according to TBIA results. The first group (= group 1) contained all clones with four TBIA-positive leaves and the second group (group 2) contained all clones with at least one TBIA-negative leaf. We may assume that clones belonging to group 1 were more susceptible to SCYLV than clones belonging to group 2.

The frequency of RT-PCR-positive clones was compared within these two groups (Table 4), and it was significantly higher in group 1 that included the most susceptible clones as determined by TBIA. The incidence of each SCYLV genotype within the RT-PCR positive leaves was then compared between groups 1 and 2. Incidence of genotype CUB was not different in group 1 and group 2.

The same result was found for SCYLV genotype BRA-PER. In contrast, the frequency of REU genotype varied between the two groups (P = 0.014): 56% and 25% for groups 1 and 2, respectively. This latter result suggested that SCYLV genotype REU is able to infect the susceptible clones more easily than the other ones.

<table>
<thead>
<tr>
<th>RT-PCR primers</th>
<th>Test result</th>
<th>Clones with no virus-free leaves</th>
<th>Clones with at least one virus-free leaf</th>
<th>P = (Fisher’s exact test)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCYLV generic primers</td>
<td>+</td>
<td>100</td>
<td>20</td>
<td>1 ×10⁻⁵</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>5</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>CUB specific primers</td>
<td>+</td>
<td>72</td>
<td>14</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>28</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>REU specific primers</td>
<td>+</td>
<td>56</td>
<td>5</td>
<td>0.014</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>44</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>BRA-PER specific primers</td>
<td>+</td>
<td>21</td>
<td>6</td>
<td>0.387</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>79</td>
<td>14</td>
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</tr>
</tbody>
</table>

**Interaction between genotypes**

Because CUB was the most frequent genotype in the studied population, the incidence of genotypes REU and BRA-PER in CUB positive and CUB negative leaves was investigated. The incidence of genotype REU in CUB positive and CUB negative leaves was 44% and 45%, respectively. The frequency of genotype BRA-PER in CUB positive and CUB negative leaves was 15% and 28%, respectively, but this difference was not significant (P = 0.11).

**Discussion and conclusion**

A very high percentage of sugarcane clones of the selection plot (93%) were found infected with SCYLV, indicating rapid infection of plants after planting the seedlings a few years ago (assuming that SCYLV cannot be transmitted through true seed or fuzz; Rott et al., 2008). This situation is completely different from the situation observed in commercial fields in Guadeloupe where only few plants (0.5–37 %) were found infected by the virus (Daugrois et al., 2008). However, high incidence of SCYLV in commercial cultivars was described in Hawaii (Schenck and Lehrer, 2000) and in Réunion Island.

In this latter location, almost all plants of cultivar R575 were infected with the virus (Rassaby et al., 2004). The high variation of SCYLV incidence between CIRAD’s breeding station in Guadeloupe and commercial fields could be attributed to low resistance to yellow leaf of the sugarcane cultivars used as parents in the crossings. This hypothesis is supported by our data suggesting that the genetic background of the crosses used in the selection plot played a role in the
number of RT-PCR positive leaves (presence of the virus) and the number of leaves harbouring the different virus genotypes. This situation should be taken into account in breeding sugarcane for resistance to SCYLV.

Furthermore, the nature and dynamics of aphid vector populations might also account for the striking differences between the sugarcane selection plot and commercial fields in Guadeloupe (Edon Jock, 2008). SCYLV genotype REU was more frequently detected in the group of sugarcane clones considered as the most susceptible (all four analysed leaves tested positive by TBIA) than in the other group of clones (at least one leaf tested negative by TBIA).

This result is in agreement with previous experiments performed in Guadeloupe in which genotype REU was less aggressive than the other virus genotypes (Abu Ahmad et al., 2007).

The most frequent virus genotype in the selection plot was CUB, whereas genotype REU is the most frequent, if not to say the only one, in commercial fields of Guadeloupe. Additionally, a high proportion of leaf samples were co-infected with two different virus genotypes. We even found four single leaves (representing two clones) in which the three genotypes were present together.

The detection of all three SCYLV genotypes in a single plant is most likely related to the setup of the selection plot on a research station where sugarcane clones and genetic resources have been introduced for a long time, especially when sugarcane yellow leaf was unknown and/or when efficient detection tools were not available. It would be interesting to investigate whether the situation observed in Guadeloupe is unique or encountered in other locations where breeding stations are used to produce and select new cultivars.

This study shows that SCYLV genotype CUB has a better fitness than genotypes BRA-PER and REU among the breeding progenies of the selection plot in Guadeloupe. The reasons that account for this better fitness should be further investigated. Interestingly, the detection of genotype CUB remained confidential until very recently in Guadeloupe (Daugrois et al., 2008).

Occurrence of genotype CUB may have been underestimated because the detection primers that were used up to recently failed to detect this genotype in several circumstances (Girard et al., 2008). Alternatively, its occurrence may be very recent and, therefore, genotype CUB may be an emerging genotype in Guadeloupe.

The high proportion of leaves in which two different virus genotypes (and even three genotypes in four leaves) were detected suggests that the presence of one genotype in a plant does not prevent infection by another genotype in the same plant. These multiple infections were most likely favoured by the planting of clones near SCYLV-infected sugarcane germplasm and in the presence of large and active aphid populations.

To conclude, the results of this experiment give rise to at least two important questions: 1/ Does this situation, observed on a sugarcane breeding station, dictate the disease situation in sugarcane commercial fields within the next several years?, and 2/ Will the co-existence of two or three different SCYLV virus genotypes in the same plants promote the genesis of new virus genotypes that could be more virulent? Large fields of investigations regarding yellow leaf of sugarcane remain unexplored or insufficiently explored so far.

Acknowledgments

We would like to express our thanks to Dr Monique Royer for designing the new SCYLV primers used in this study.

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DIVERSITE GENETIQUE DU SUGARCANE YELLOW LEAF VIRUS DANS UNE PARCELLE DE SELECTION DE CANNE A SUCRE EN GUADELOUPE

Par

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MOTS CLEFS: SCYLV, Génotypes.

Résumé

La diversité génétique du Sugarcane yellow leaf virus (SCYLV) a été étudiée dans une parcelle de sélection de canne à sucre en Guadeloupe pour déterminer l’incidence des différents génotypes connus du virus (BRA-PER, CUB and REU) dans une descendance. Quatre feuilles F1 ont été collectées au hasard sur chacun des 154 clones de canne à sucre et testées pour la présence de SCYLV par la technique d’immuno-empreintes (TBIA). Les échantillons foliaires ont été stockés à –80°C en attendant l’extraction de l’ARN total des feuilles infectées par le SCYLV. Les génotypes du virus ont été déterminés par RT-PCR en utilisant des paires d’amorces spécifiques de chaque génotype. Quatre-vingt-deux pour cent des feuilles testées étaient infectées par SCYLV et tous les génotypes connus du virus étaient présents dans la parcelle de sélection. La majorité des plantes étaient infectées par les génotypes CUB ou REU, ou par un mélange de ces deux génotypes. Cette situation est totalement différente de celle observée dans des champs commerciaux en Guadeloupe où l’incidence du SCYLV est beaucoup plus faible, et où la plupart des plantes sont infectées par le génotype REU. La signification de cette situation surprenante fera l’objet d’autres études.
DIVERSIDAD GENÉTICA DEL SUGARCANE YELLOW LEAF VIRUS EN UNA PARCELA DE SELECCIÓN DE CAÑA DE AZÚCAR EN GUADELOUPE (FWI)

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PALABRAS CLAVES: SCYLV, Genotipos.

Resumen
La diversidad genética del Sugarcane yellow leaf virus (SCYLV) fue investigada en una parcela de selección de caña de azúcar en Guadalupe (FWI = Caribe francés) para establecer la incidencia de diferentes genotipos conocidos de este virus (BRA-PER, CUB y REU) en una descendencia. Cuatro hojas F1 (primera hoja totalmente desarrollada) fueron recolectadas al azar sobre cada uno de los 154 clones de caña de azúcar y la presencia de SCYLV fue determinada con la técnica de ‘tissue blot immunoassay’ o TBIA. Las muestras de hojas fueron almacenadas a –80°C y el ARN total fue extraído de las hojas infectadas por el SCYLV. Los genotipos del virus fueron determinados por RT-PCR utilizando tres pares de cebadores específicos de cada genotipo. Un ochenta y dos por ciento de las hojas analizadas estaban infectadas por el SCYLV y todos los genotipos conocidos del virus estaban presentes en la parcela de selección. La mayor parte de las plantas estaban infectadas por los genotipos CUB o REU, o por una mezcla de estos dos genotipos. Esta situación es totalmente diferente a la observada en los campos comerciales en Guadalupe donde la incidencia del SCYLV es mucho más baja y donde la mayoría de las plantas están infectadas por el genotipo REU. Las causas de esta situación asombrosa serán investigadas más adelante.
ORANGE RUST DISEASE OF SUGARCANE

By

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KEYWORDS: Orange rust, Puccinia kuehnii, Resistance, Early Warning, Fungicides.

Abstract

An outbreak of orange rust (Puccinia kuehnii) in the Australian sugarcane industry in 2000 caused devastating yield losses and significant financial hardships to cane farmers, sugar factories and the local communities that were reliant on the crop. The epidemic was first recognised in the year 2000, but later analyses suggest that orange rust was present in central (Mackay) region crops at least 1–2 years (in 1998–1999) prior to detection. This was evident in comparative sugar factory productivity data for several varieties and in yield loss analyses in breeding selection trials. Yield loss studies (breeding selection trials and fungicides) suggested losses of around 40% from orange rust. Resistance assessments showed there to be a high level of disease resistance in many commercial varieties. Fungicide research led to the application of fungicides to commercial crops to minimise yield losses. Large quantities of resistant seed-cane were transported long distances from neighbouring regions to assist farmers in replanting susceptible crops. Genetic analyses suggested that there were minor variations in the pathogen ‘pre-’ and ‘post-epidemic’; some variation was observed in pathogen isolates collected from its geographical range around the world. Possibilities for remote detection of the disease were investigated and techniques could be used to provide early warning of the presence of the disease.

Introduction

Recent detections of orange rust (Puccinia kuehnii) in North and Central America have continued to emphasise the new-found importance of this disease in commercial crops.

Originally restricted to south Asia, south east Asia, and the Pacific (Ryan and Egan, 1989; Magarey et al. (2002b, 2003a)), the disease has now been detected in the western hemisphere in North and Central America (Chavarria et al. (2009), Comstock et al. (2008), Ovalle et al. (2008), Flores et al. (2009)).

Australian evidence suggests that the recent outbreak, as reported by Magarey (2000), Magarey et al. (2001a, 2001b, 2002a, 2003b), are more serious than those occurring earlier in history.

A new, more aggressive strain of the pathogen may be the reason for these observations (Braithwaite et al., 2009).

In this paper, epidemiological considerations associated with the disease, the major effects of orange rust, the framework used in Australia for implementation of management strategies, potential early warning techniques and the presence of disease resistance in Australian germplasm are reviewed.
History of Orange Rust in Australia

Orange rust has been reported within the Australian sugarcane industry since the late 1800s, though the accuracy of some disease records has been questioned (Ryan and Egan, 1989). With the disease common in neighbouring Papua New Guinea, the centre of diversity of several *Saccharum* species, it is likely that orange rust entered Australia with PNG germplasm. Despite this, 20\textsuperscript{th} century reports of diseased commercial crops were rare. When brown rust (*Puccinia melanocephala*) first entered the Australian industry in 1978, that disease became known as ‘rust’ – there was no recognised need to distinguish brown rust from orange rust in commercial crops emphasising the minor importance of orange rust. As such, there were no purposeful orange rust disease assessments, screening for resistance, or regular reporting of the area affected in commercial crops.

Strains of *Puccinia kuehnii*

The rapid appearance of the disease in a widely-planted variety that had for a number of years shown no evidence of the disease lent weight to the hypothesis that the epidemic arose from a new pathogen strain. Molecular analysis of historical Australian samples (1898), samples collected from Indonesia, Papua New Guinea, Central America and from within the Australian sugarcane industry could not clearly pinpoint the nature of the strain change, but did show pathogen variation (Braithwaite *et al.*, 2009).

Braithwaite *et al.* (2009) concluded that isolates from commercial crops clustered together and this included the 1898 Australian isolate plus more recent isolates. Two other clades (groups) included *P. kuehnii* isolates from wild and garden canes in Indonesia and PNG. Though morphologically similar to *P. kuehnii*, there was more variation in these samples and they pose a potential further threat to the Australian (and other) sugarcane industry. They concluded there is a greater diversity in *P. kuehnii* isolates than thought previously (Braithwaite *et al.*, 2009).

Orange Rust epidemic in 2000

The status of orange rust changed in the year 2000 with its detection in the widely-planted commercial Australian variety, Q124. The epidemic was severe, crop canopies were largely dead, and biomass production stifled. Many very poorly-grown crops were present in the central (Mackay) region; symptoms included thin, rubbery, pithy, shortened stalks and senescing leaves.

Farmers venturing into their fields on machinery emerged with orange-coloured shirts and hats, and there were reports of concrete veranda floors covered with an orange film. Urgent action was needed to minimise crippling yield losses, and a major industry program involving research, strategic economic incentives and on-farm strategies was implemented to minimise economic effects.

Orange rust was first reported in Q124 crops in January 2000 in the Mackay district of central Queensland. Q124 is susceptible to yellow spot (*Mycovellosiella koepkei*) disease and previous high rainfall years favoured this disease. Observations in January 2000 suggested, however, that the observed symptoms were different to those of yellow spot; samples were dispatched to a pathologist who identified the disease as orange rust based on pustule and spore characteristics.

Rapid escalation in disease severity accompanied progress of the normal wet season and reports soon came of the disease in most other parts of the industry, including northern, Herbert, Burdekin and southern production areas. Orange rust was not seen in the southern-most Australian production area of northern New South Wales until the following year. By March 2000, the regions where Q124 was widely planted (central and Herbert) were badly affected with crop canopies in very poor health. Crops yields plummeted compared to previous years and individual farmers, sugar factories and service companies all were badly affected financially.
Evidence for early incidence

There is strong evidence that the disease first affected sugarcane crops in the central district before January 2000, there being two lines of evidence. Yield loss assessments in BSES plant improvement selection trials showed a relationship between orange rust resistance and yield in 1999-harvested crops in the central part of the Mackay district (Magarey et al., 2009a).

These losses were not seen further afield but in central Mackay trials only. Additionally, relative commercial crop yields in two significant Mackay varieties (one susceptible during the epidemic (Q124) and one that remained resistant (Q135)) showed that Q124 very significantly out-yielded Q135 in the mid-1990s, but by 1998 a trend to lower relative yield in Q124 emerged; the difference grew significantly post-2000.

With the presence of two leaf diseases, it is reasonable to conclude that orange rust was not detected in Q124 for 1–2 years. Close observation of individual leaves is needed to separate orange rust from yellow spot and this didn’t occur until orange rust severity rose significantly.

This provides an object lesson – that vigilant crop observations by pathologists trained in endemic and exotic diseases are needed to ensure an early warning of impending disease epidemics.

Yield loss research

Yield loss data have been published elsewhere, but a brief summary provides an indication of the extent of losses.

Breeding selection trials

Breeding selection trial analyses are based on relating the yield of a range of clones (80+) to their orange rust resistance in individual trials (Magarey et al., 2003b). The technique has been used to quantify yield losses caused by a range of endemic Australian diseases (Magarey et al., 2003b, 2009a).

Losses at individual sites in the Mackay region in the year 2000 reached 58% (tonnes cane / ha), though the mean figure was around 40%.

This was further emphasised by the relative performance of Q124 within selection trials; before 2000 Q124 was the most productive variety but, during and after 2000, it became one of the lowest yielding (Magarey et al., 2003b). Losses were not restricted to biomass, but included sugar content (CCS) with a reduction of 1 to 2 units.

Fungicide studies

Fungicide studies have also been reported elsewhere (Magarey et al., 2002a; Staier et al., 2003). Several experiments undertaken near Mackay showed yield improvements between treated and untreated plots of 40%, reinforcing the selection trial estimates. Reductions in sugar content of around 1–2 units again were reported (Staier et al., 2003).

Management of the epidemic

Magarey et al. (2001a) report on the management strategies associated with the epidemic. A focused, industry-based strategy, implemented as soon as the epidemic was recognised, greatly assisted with epidemic management.

The main components were:

i. the supply of orange rust resistant varieties that were free of systemically transmitted pathogens, from as far afield as 500 km away,

ii. the acceleration of resistant clones within the plant improvement program,

iii. the gaining of resistance data on both clones and parent canes and modified selection and crossing programs, and

iv. the application of effective fungicides to susceptible crops, thus minimising losses during the establishment of resistant crops.
Varieties

There was no problem identifying susceptible clones in variety trials in badly affected districts; senescing crop canopies in very poor health were very obvious. Quantitative resistance screening techniques were developed which utilised comparative standard varieties of known disease reaction (Magarey and Bull, 2009). Plant breeders discarded susceptible clones from selection programs and pathologists screened parent varieties for resistance to ensure suitably resistant crosses were made between parents (Magarey and Bull, 2009). Data showed that a high level of resistance was present within the Australian sugarcane germplasm (Magarey et al., 2003b; Magarey et al., 2009a, Magarey, 2006). The replacement of the highly susceptible Q124 in district crops effectively ended the epidemic. It has not been difficult since then for plant breeders to release high-yielding commercial varieties possessing a high level of disease resistance.

In the central and Herbert (the two most affected) districts, planting material of replacement resistant varieties was quickly made available in 2000 and 2001. The Mackay sugar factories offered financial incentives for farmers to replant susceptible crops with resistant varieties and the economics of the situation drove a rapid transition to resistant crops. In other districts, the situation was not as severe and farmers transitioned to resistant crops without direct assistance.

Fungicides

There have been no historical fungicide applications for leaf disease control in Australian crops. In fact, there are only rare reports of this on a world basis (Autrey et al., 1983). The need for a rapid disease control was so urgent in the Mackay region that widespread fungicide application occurred in-lieu of transition to resistant varieties. Staier et al. (2003) report on research undertaken in 2001 with the fungicides propiconazole, cyproconazole and mancozeb. Good control was achieved with as little as two spray applications, as long as the applications were made sufficiently early (when leaf area diseased reached 5%). Knowledge of the effect of weather conditions (Magarey et al., 2004, Staier et al., 2004) and predictive modelling assisted in minimising fungicide applications. The products were granted temporary registration and over 30 000 ha treated (Staier et al., 2003). Aerial applications were undertaken in 2001, but low sugar prices and the successful transition to resistant canes led to no, or very limited, further fungicide applications in the following years.

Epidemic considerations

Previous disease epidemics in Australia

There have been many disease epidemics in the Australian sugarcane industry, including those caused by sugarcane mosaic, leaf scald, Fiji leaf gall, brown rust, Pachymetra root rot and more recently sugarcane smut. Almost all began when the affected region had been widely cropped with one variety for a period of around 10 years.

Examples include Fiji leaf gall in southern Queensland where NCo310 dominated plantings (>80% of crops) for at least 10 years (Egan, 1982). The variety Q90 was widely planted in the northern region (>60% production) in the 1970–1980 period before Pachymetra root rot and brown rust both drastically reduced commercial yields. In central Queensland, the highly productive Q124 was widely grown, and constituted >80% of the regional production before the orange rust outbreak. It seems that whenever a single variety exceeds, on an extended basis, approximately 60% of production, a disease epidemic is initiated.

Progress of the orange rust epidemic

Progress of the orange rust epidemic was very rapid; the disease spread the length of the Australian sugarcane industry (approximately 2100km) in just over 12 months – though pre-detection disease occurrence suggests spread is likely to have begun in 1998 or 1999. Similar spread was observed with the Australian brown rust incursion; Ryan and Egan (1989) reported that P. melanocephala also spread through the industry within 12 months.
In contrast, spread of Fiji leaf gall (Egan, 1982) and sugarcane smut (Magarey et al., 2009b) have been much slower thus allowing more time for the transition to resistant varieties. The slower spread is no doubt a consequence of the involvement of a slower spreading vector with limited infective ability (Fiji leaf gall) and the limited target infection court for sugarcane smut (compared to orange rust). The orange rust yield effects quickly drove Mackay region farmers to transition to more resistant varieties and this is illustrated in Figure 1.

![Fig. 1—The orange rust crop resistance profile for Central Queensland 1995–2009: this provides a measure of the average resistance of crops grown in the region. The 2000 epidemic greatly influenced farmer variety choice, thus leading to a sudden surge toward resistant crops.](image)

Comparison to smut

Smut has not spread as quickly (Magarey et al., 2009b). The lower initial percentage of smut resistant varieties in the Australian industry has made the smut epidemic variety transition more difficult. Magarey et al. (2009b) suggest that smut will spread across an individual region (to reach all farms) within 2–3 years from first detection and will build up approximately 10-fold annually leading to very significant yield losses in susceptible crops 2–3 years from the first crop detection in that crop.

Remote detection

Mackay Sugar Limited (operating Mackay sugar factories) cooperated with researchers to develop remote sensing systems for orange rust detection (Apan et al., 2004). Several methodologies were investigated.

The authors concluded that accessing hyperion imagery enabled the remote detection of diseased crops possible. This offers other sugarcane industries scope for early detection of orange rust in order to speedily introduce appropriate management systems. Magarey et al. (2008, 2009c) found that spore trapping using commercial spore traps (‘spore and pollen samplers’, Burkard, England) could provide up to 24 months early warning for the presence of sugarcane smut (previous to the finding of field symptoms in a region). The system they used incorporated a specific molecular assay to confirm the presence of *Ustilago scitaminea* spores on trap tapes; similar systems could be developed for orange rust with assays specific to *P. kuehnii*.

Discussion

The Australian sugarcane industry suffered very significant financial losses in the midst of the orange rust epidemic in the 2000–2002 period. These losses were greatly contributed to by industry reliance on a single, high yielding variety, Q124. The relative abundance of high-yielding resistant varieties enabled a rapid transition to resistant commercial crops, and now the disease provides no direct financial constraint to sugarcane production.
Following the epidemic, there has been considerable discussion on the benefits / disadvantages of cropping a large proportion of a region to one specific variety. Such a strategy involves considerable risk to both farmers and factories from the potential occurrence of a disease epidemic. Australian experience lends credence to the view that the widespread planting of a single variety will lead to a disease epidemic. However, economic analyses suggest if a variety is of unparalleled productivity, the local sugarcane industry may make greater monetary returns by taking the risk and growing individual varieties until no longer possible because of disease-associated yield losses. Discussions on limiting variety production gathered momentum in Australia following the orange rust outbreak, but there has been no implementation. Previous high financial returns don’t always provide a viable way forward when a disease epidemic hits. When the orange rust epidemic occurred, factory through-puts were suddenly cut and immediate financial returns were drastically reduced, making it very difficult for some factories, farmers and local businesses to remain viable.

The widespread planting of single varieties may also lead to fundamental changes in pathogen populations and the predominance of hitherto minor pathogens. The longer-term costs and implications of this are not always considered. Is it the new strain of *Puccinia kuehnii* that developed in Australian Q124 crops the one that has now invaded Central and North America? Would this have happened if Q124 had not been so widely planted in Australian cropping regions? These and other questions remain to be answered.

REFERENCES


LA ROUILLE ORANGÉE DE LA CANNE À SUCRE

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Résumé

UNE EPIDEMIE de la rouille orangée (*Puccinia kuehnii*) dans la culture de la canne à sucre en Australie en 2000 a causé des pertes importantes et des difficultés financières aux planteurs de canne, sucreries et communautés locaux qui dépend de cette culture. L’épidémie a été constatée en 2000, mais les analyses ultérieures tendent à montrer que la rouille orangée était présente dans la région centrale (Mackay) depuis au moins 1–2 ans (en 1998-1999) avant sa détection. Cela était évident à partir des données comparatives des sucreries sur la productivité de plusieurs variétés ainsi que de l’analyse des pertes de rendement dans les essais de sélection. Les études de l’effet de la rouille orangée sur le rendement (essais de sélection variétale et de fongicides) ont démontré des pertes d’environ 40%. L’évaluation des variétés pour la résistance a montré un niveau de résistance élevé parmi plusieurs variétés commerciales. La recherche sur les fongicides a conduit à une application des fongicides dans plusieurs plantations industrielles afin de minimiser les pertes de rendement. Une importante quantité de boutures des variétés résistantes a été transportée sur de grandes distances des régions avoisinantes pour aider les fermiers à remplacer les variétés sensibles. Les analyses génétiques n’ont montré que des variations mineures dans le pathogène, avant et après l’épidémie, alors qu’une certaine variabilité a été observée parmi les isolats du pathogène collectés sur son étendue géographique à travers le monde. La possibilité de téldétection de la maladie a été étudiée et des techniques pourraient être mises en place comme moyen d’alerte précoce de la présence de la maladie.
ENFERMEDAD DE LA ROYA NARANJA
DE LA CAÑA DE AZÚCAR

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PALABRAS CLAVE: Roya Naranja, Puccinia kuehnii, Resistencia, Alarma Temprana, Fungicidas.

Resumen
EN EL 2000, el brote de roya naranja (Puccinia kuehnii) causó severas pérdidas tanto en el campo como en las fábricas y serias dificultades financieras a los cultivadores y todas las comunidades relacionadas con el cultivo de la caña de azúcar. La epidemia se reconoció como tal en el año 2000, pero análisis posteriores demostraron que la roya naranja estaba presente en la regional central (Mackay), al menos durante 1–2 años (en 1998–1999) antes de esta fuera detectada como tal. Esto fue evidente en los análisis comparativos de productividad de varias fábricas y diversas variedades así como por las pérdidas en productividad de las diversas pruebas del proceso de mejoramiento. Los estudios sobre pérdidas en productividad (pruebas del proceso de mejoramiento como con fungicidas) indicaron que éstas fueron alrededor del 40% debido a la roya naranja. Las evaluaciones de resistencia mostraron que existe un alto nivel de resistencia a la enfermedad en muchas variedades comerciales. La evaluación de fungicidas llevó a su aplicación en muchos cultivos comerciales para reducir al mínimo las pérdidas en productividad. Grandes cantidades de semilla de variedades resistentes fueron transportadas a grandes distancias para ayudar a los cultivadores en el replante de cultivos susceptibles. El análisis genético sugiere que existen pequeñas variaciones en el patógeno ‘pre-’ y ‘post-epidemia’, puesto que se encontraron ligeras diferencias entre los aislamientos recolectados en diferentes regiones del mundo. Las posibilidades de detección temprana de la enfermedad fueron investigadas así como las técnicas que se podrían utilizar para proporcionar una alerta temprana sobre la presencia de la enfermedad.
ADVANCE IN GENETIC IMPROVEMENT TO RESISTANCE
OF SUGAR CANE TO XANTHOMONAS ALBILINEANS (ASHBY)
DOWSON IN CUBA

By

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KEYWORDS: Leaf Scald,
Sugar Cane, Resistance Test.

Abstract

LEAF SCALD, caused by X. albilineans, is a quarantined disease in Cuba and not much is
known on how it behaves under the environmental conditions of the country. Because
of this, we did a molecular characterisation of the inoculum employed to artificially
inoculate sugarcane plants at two varietal resistance trials and we developed a scale to
characterise the severity of the infection in the progeny The work has allowed progeny
evaluation of the families resulting from the hybridisation program for their reaction to
leaf scald. The months of September and October were the best times to plant genotypes
for selection and evaluation of leaf scald resistance.

Introduction

Leaf scald, caused by Xanthomonas albilineans (Ashby) Dowson, was first reported in Cuba
at the end of the 1970s.

During 1978–1982, leaf scald was detected in 14 foci scattered through 7 provinces of the
country (Rivera et al., 1979).

Years later, X. albilineans was detected in latently infected plants obtained through tissue
culture and in commercial plantations. The danger of a resurgence of the disease was pointed out
(Peralta et al., 1997).

Leaf scald is found in more than 54 countries and, during recent years, there have been
several outbreaks in different cane areas of the world, with significant losses being reported in
highly susceptible varieties (Rott and Davis, 2000).

The most effective methods used by geneticists and plant pathologists to control the disease
have been the use of resistant varieties and the use of healthy seed.

Because leaf scald has been reported to be influenced by the environment, there is a need to
study the different phytopathological principles that determine the behaviour of leaf scald in Cuba
and to obtain a greater efficiency in identifying new resistant varieties.

Materials and methods

The research was done at two research centres: one for the study of the diseases in Cuba,
part of the Provincial Sugar Cane Experiment Station of Camaguey located in Tayabito, on a brown
soil with carbonates, using two different planting times, March (Cycle A) and September (Cycle C),
and the second at the Matanzas Sugar Cane Experiment Station in Jovellanos on a red ferrous soil,
using the same planting cycles.
The methodology and experimental design were directed towards phytopathological concepts necessary to work with the disease caused by *X. albilineans* under Cuban conditions consisting of the following phases:

- Characterisation of isolates of *Xanthomonas albilineans* using AFLP, at two experiment stations in Cuba studying the disease.
- Determination of an evaluation scale to characterise the different disease reactions.
- Determination of the periods and times of greater occurrence of the disease under Cuban environmental conditions.

**Characterisation of isolates of *Xanthomonas albilineans* through AFLP at the two test centres for the disease in the country**

*Bacterial cultures* The bacterial cultures were centrifuged at 5000 rpm for 20 min and the sediment was used for the purification of the genomic DNA utilising the commercial method and reagents Wizard Genomic DNA (cat #A1120, Promega, USA). The integrity of the DNA was verified with agarose gels (0.8%) visualised with EtBr.

*Genomic Analysis* Genomic analysis was done by means of Amplified Fragment Length Polymorphism (AFLP) following the procedure described by Vos *et al.*, (1995) and according to European Patent 0534858 (Keygene, Belgium).

**Determination of an evaluative scale for the characterisation of the different effects caused by the disease**

To examine the role of bacterial concentration on genotypes resistance, as well as to define an evaluation scale, the study was divided into 4 fundamental aspects:

1. Define the symptoms and the severity of the infection.
2. Determine the dilutions required to make the counts of colony making units (ufc).
3. Compare the number of ufc in symptomatic and asymptomatic plants.
4. Determine the relationship between the ufc and the severity of the infection.

Afterwards, monthly evaluations were done, registering the number of plants with each degree of intensity in the scale that the proper methodology establishes. Having information on the severity of the disease and in order to differentiate intermediate responses from the varieties to this pathogen, a discriminant analysis was conducted.

**Determining the seasonal periods of greater occurrence of leaf scald under Cuban environmental conditions.**

The resistance against leaf scald of 377 new varieties of sugarcane and check varieties, (My5514, resistant; L 55-5, susceptible), was tested, utilising two different periods, Fall (September) and Spring (March), of planting and inoculation.

**Results and discussion**

Molecular characterisation of the samples of DNA of *Xanthomonas albilineans* analysed by means of AFLP with the combination of primers P (PstI) and M (MseI) is shown in Figure 1.

In the 4 combinations used, a great consistency and resolution of the amplified bands of DNA was observed.

The sections of gels with the greater resolution show they were amplified with different intensities, approximately 38 bands for the combination of primers A, 39 bands for B, 34 bands for C and 37 bands for the combination D.

At the same time, in all cases, a high similarity in the amplification bands is demonstrated and polymorphic bands of DNA were not identified.

The conclusion was that, under the conditions of this work, no significant variability was detected, demonstrating that both cultures are similar at this genomic level. Table 1 shows the primers used, and Figure 1 shows the amplification bands.
Table 1. Primers utilised in reactions of AFLP.

<table>
<thead>
<tr>
<th>Code</th>
<th>Primers</th>
<th>Sequence the primers DNA</th>
<th>Kiss selective</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>Pstl-1</td>
<td>5’GACTGCGTACATGCA.3´</td>
<td>aa</td>
</tr>
<tr>
<td>P2</td>
<td>Pstl-2</td>
<td>5’GACTGCGTACATGCA.3´</td>
<td>ac</td>
</tr>
<tr>
<td>M1</td>
<td>Mse1-1</td>
<td>5’GATGAGTCCTGAGATAC.3´</td>
<td>acc</td>
</tr>
<tr>
<td>M2</td>
<td>Mse2-1</td>
<td>5’GATGAGTCCTGAGATAC.3´</td>
<td>ggc</td>
</tr>
</tbody>
</table>

Copy of primers
A. P1/M1
B. P1/M2
C. P2/M1
D. P2/M2

Isolations: (1. Jovellanos, 2. Camagüey)

Fig. 1—Amplification bands (AFLP) using 4 combinations of primers from cultures of the pathogen *Xanthomonas albilineans* from Matanzas and Camaguey provinces.

With no differences detected in the inocula used in the two Test Centres, a rating scale was developed for use under Cuban environmental conditions.

Based on a review of the results of the severity of the infection on plant cane and on ratoon crops and after applying the discriminatory analysis, 5 groups of varieties were characterised, based on their response to the infection (Table 2).

The definitive groups were decided on the maximum severity of infection shown in any of the evaluations on both ages of the crop.

Table 2—Degrees of severity of the infection to be used in the evaluation of leaf scald.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Denomination</th>
<th>Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Plant</td>
</tr>
<tr>
<td>1</td>
<td>Very resistant</td>
<td>0–2</td>
</tr>
<tr>
<td>2</td>
<td>Resistance fighters</td>
<td>2.1–10</td>
</tr>
<tr>
<td>3</td>
<td>Intermediate</td>
<td>010.1 2</td>
</tr>
<tr>
<td>4</td>
<td>Susceptible</td>
<td>20.1–30</td>
</tr>
<tr>
<td>5</td>
<td>Very susceptible</td>
<td>30</td>
</tr>
</tbody>
</table>

Resistants, Intermediates, Susceptibles
When the group of varieties showing the greatest severity of infection in the ratoon stage was examined, it was noted that when the severity did not go over 10%, neither has the level exceeded 10% in the plant cane stage, emphasising the criteria of several researchers that the 10% level of severity could be the limit of expression of resistance in leaf scald.

An interesting element of concern is determining those times when the disease presents itself with greatest incidence in Cuba, thus making it possible to evaluate varieties more efficiently.

A comparison of the effect of the disease on both ages of the cane, whether as plant cane or ratoon, in relation to their classification degree can be seen in Figure 2. As can be seen, material planted in September showed greater damage by the disease as plant cane, whereas those planted in March showed greater losses as ratoon crop, which indicates that genotypes in September plantings can be evaluated quicker, but it is evident that both planting dates should be evaluated.

![Fig. 2—Comparison of the effect of the disease in relation to both age of the crop (plant cane and ratoon) and different planting dates (fall and spring).](image)

**Conclusions**

- Isolates of *Xanthomonas albilineans* used in the two Test Centres for varieties and parents in Cuba are similar at this genomic level; therefore, the information that is obtained can be extrapolated.
- A new scale showing different degrees of the severity of leaf scald infection is now available for Cuba.
- In fall planted cane (September), individuals can be separated as per their resistance without the need to get to the ratoon stage; to get more conclusive results, both plant cane and ratoons should be evaluated.

**REFERENCES**


LES AVANCÉES DE L’AMÉLIORATION GÉNÉTIQUE DE LA CANNE À SUCRE POUR LA RÉSISTANCE AU XANTHOMONAS ALBILINEANS (ASHBY) DOWSON À CUBA

Par


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MOTS CLÉS: Echaudure, Canne à Sucre, Test de Résistance.

Résumé

L’echaudure, causée par *X. albilineans*, est une maladie de quarantaine à Cuba et il existe peu d’informations sur le comportement de la maladie sous les conditions environnementales prévalant dans ce pays. De ce fait, nous avons effectué une caractérisation moléculaire de l’inoculum utilisé pour l’inoculation artificielle de la canne à sucre de deux essais de résistance à la maladie et nous avons développé une échelle d’évaluation pour déterminer la sévérité de l’infection de la descendance. Cette étude a permis d’évaluer la progéniture des familles issues du programme d’hybridation génétique pour leurs réactions à l’echaudure. Les mois de septembre et d’octobre étaient les plus indiqués pour la plantation des génotypes, leurs sélections et l’évaluation de leur résistance à l’echaudure.

AVANCES EN EL MEJORAMIENTO GENÉTICO POR RESISTENCIA EN CAÑA DE AZÚCAR A XANTHOMONAS ALBILINEANS (ASHBY) DOWSON EN CUBA

Por


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PALABRAS CLAVE: Escaldadura de la Hoja, Caña de Azúcar, Resistencia.

Resumen

La escaldadura de la hoja, causada por *X. albilineans*, es una enfermedad de cuarentena en Cuba y no se sabe mucho sobre cómo se comportamiento bajo las condiciones ambientales del país. Debido a esto, se hizo una caracterización molecular del inóculo empleado para infectar artificialmente las plantas de caña de azúcar en dos ensayos de resistencia varietal, usando una escala para caracterizar la gravedad de la infección causada. El trabajo permitió evaluar la progenie de las familias derivadas del programa de hibridación en su reacción a la escaldadura de la hoja. Los meses de septiembre y octubre fueron la mejor época para seleccionar y evaluar los genotipos en su resistencia a la escaldadura de la hoja.
PHYTOSANITARY SERVICE IN THE SUGARCANE INDUSTRY IN CUBA

By

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KEYWORDS: Sugar Cane, Pest Control, Phytosanitary Service.

Abstract

Results obtained from 2000 to the present due to the implementation and generalisation of a Phytosanitary Service (SEFIT) is presented. This service has made an impact on the presence and control of pests and in moderating losses caused by them in cane production. It takes into account the active participation of the human capital inserted into the service, its qualification process, the recognition and registration of pests, pursuit of quality seed production, and developing main links to obtain healthy plants and pest control. Recommended measures take into account the biology and protection of the environment. The Service includes an automated version, unique of its type in Cuba, which allows making decisions regarding the integrated handling of harmful organisms, and consideration of the epidemiological of the strains, crop conditions, and commercial cultivars. It is also involved in the regulation of those factors presenting phytosanitary problems. The advances in the organisation of the phytosanitary service in sugarcane in our country are shown. This scientific and technical service offered by the National Sugarcane Research Institute (INICA) has shown significant benefits by preventing losses of sugar in excess of 700 000 tonnes, (market value of US$216 933), due only to smut. In addition, there were other benefits, such as lowering of indexes and percentages of infestation by pest, preventing the introduction of exotic organisms, and the reduction of rates of biological control products used to reduce incidence of pests and diseases.

Introduction

Currently, 139 pathological disorders have been reported on sugarcane worldwide, caused by pathogenic microorganisms, environmental disorders, parasitic plants and other causes. In Cuba, only 58 of these have been detected and of these, only 8 or 10 are considered of economic importance (Chinea and Rodriguez, 1994).

On the other hand, of the more than one thousand insects known to occur on sugarcane, only borers cause large economic losses to the sugar industry. Other pests of importance in Cuba are rodents, defoliating and sucking insects and nematodes.

Proper use of biological controls has resulted in decreased population levels of these pests and consequently decreased losses.

The Phytosanitary Service (SEFIT) is a new organisation created to make recommendations for recording and controlling new pests and reducing losses, with active participation of producers after receiving proper training.

Materials and methods

Results of phytosanitary research and production practices on sugarcane were compiled, and a diagnosis by visual symptoms made of the knowledge which was made available to experienced producers. Two annual samples were established in selected fields, on different plant age, time of planting and harvest, and varieties. For pest evaluation, in plant and ratoon crops, a stratified
sampling of 6 fields was conducted and the results obtained were grouped in ranges of 1–4 categories, where number 1 represented absence (INICA, 2006). With this information, a database was created and processed using an automated system.

**Results and discussion**

The information gathered from research and production data and the results from the report applied to experienced producers served as the basis for establishing the work methodology.

The development of this program raised the comprehension and execution level of actions in the implementation of the Service as well as raising the control level of pests with emphasis on environmental conservation.

From the results obtained, together with information disclosure and training, the Service was extended to all cane production areas.

This novel automated system is designed to analyse and classify pests and diseases by order of location importance, level of damage, and recommendations for control.

**Behaviour of sugarcane diseases: smut, rust and leaf scald**

Smut and rust are diseases that have been established in the country for more than two decades and remain in the first order of importance.

The management obtained by the composition of varieties, both at the national and provincial level, has allowed the reduction of these disorders.

Table 1 shows that areas affected by diseases at an intensity of severity from medium to severe has remained for the last three years in a range (percentage) of 5% in the case of smut and at not a very significant value in the case of rust and leaf scald.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Category</th>
<th>Smut</th>
<th>Area</th>
<th>%</th>
<th>Area</th>
<th>%</th>
<th>Area</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Light</td>
<td>187</td>
<td>883.14</td>
<td>33.34</td>
<td>188</td>
<td>389.61</td>
<td>35.99</td>
<td>187</td>
</tr>
<tr>
<td>3</td>
<td>Medium</td>
<td>6300.</td>
<td>65</td>
<td>1.12</td>
<td>10</td>
<td>771.85</td>
<td>2.06</td>
<td>14</td>
</tr>
<tr>
<td>4</td>
<td>Intense</td>
<td>16</td>
<td>572.43</td>
<td>2.94</td>
<td>15</td>
<td>229.11</td>
<td>2.91</td>
<td>14</td>
</tr>
</tbody>
</table>

**Rust**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Category</th>
<th>Area</th>
<th>%</th>
<th>Area</th>
<th>%</th>
<th>Area</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Light</td>
<td>92 632.01</td>
<td>16.44</td>
<td>85 805.95</td>
<td>16.39</td>
<td>110 768.47</td>
<td>18.88</td>
</tr>
<tr>
<td>3</td>
<td>Medium</td>
<td>396.07</td>
<td>0.07</td>
<td>707.43</td>
<td>0.14</td>
<td>872.46</td>
<td>0.15</td>
</tr>
<tr>
<td>4</td>
<td>Intense</td>
<td>291.89</td>
<td>0.05</td>
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<td></td>
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</tbody>
</table>

**Leaf scald**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Category</th>
<th>Area</th>
<th>%</th>
<th>Area</th>
<th>%</th>
<th>Area</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Light</td>
<td>566.69</td>
<td>0.11</td>
<td>213.74</td>
<td>0.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Medium</td>
<td>107.20</td>
<td>0.02</td>
<td>383.83</td>
<td>0.07</td>
<td>147.98</td>
<td>0.03</td>
</tr>
<tr>
<td>4</td>
<td>Intense</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

In the case of diseases, recommendations such as proper management and planting of resistant varieties, together with diversification with other field and forestry crops in the cane growing areas, have contributed to a reduction in the inoculum pressure in the ecosystem.

**Behaviour of insect pests and rodents**

Borers and rodents constitute the most harmful species to sugarcane in Cuba. In the period in which their presence was analysed (Medium + intense), the area of intense infestation did not exceed 7% of the sampled area for *Diatraea saccharalis* and 16% for rats, the latter maintaining a similar status as the one reported in previous years.

This result has been favoured by the recommendations and the campaigns of liberation of biological controls, as well as the elimination of rats in cane areas, infrastructures and towns nearby. The defoliators and elaterids have not shown attacks of significance (Table 2)
Table 2—National distribution of insects pests and rodents (acres).

<table>
<thead>
<tr>
<th>Grade</th>
<th>Category</th>
<th>Borers</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Area</td>
<td>%</td>
<td>Area</td>
<td>%</td>
</tr>
<tr>
<td>2</td>
<td>Light</td>
<td>165 895.29</td>
<td>29.43</td>
<td>193 304.45</td>
<td>36.93</td>
</tr>
<tr>
<td>3</td>
<td>Medium</td>
<td>28 328.72</td>
<td>5.03</td>
<td>32 865.43</td>
<td>6.28</td>
</tr>
<tr>
<td>4</td>
<td>Intense</td>
<td>34 544.12</td>
<td>6.13</td>
<td>25 481.89</td>
<td>4.87</td>
</tr>
<tr>
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<table>
<thead>
<tr>
<th>Grade</th>
<th>Category</th>
<th>Defoliators</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Area</td>
<td>%</td>
<td>Area</td>
<td>%</td>
</tr>
<tr>
<td>2</td>
<td>Light</td>
<td>32 749.93</td>
<td>5.81</td>
<td>36 818.16</td>
<td>7.03</td>
</tr>
<tr>
<td>3</td>
<td>Medium</td>
<td>96.10</td>
<td>0.02</td>
<td>602.51</td>
<td>0.12</td>
</tr>
<tr>
<td>4</td>
<td>Intense</td>
<td>112.57</td>
<td>0.02</td>
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</table>

<table>
<thead>
<tr>
<th>Grade</th>
<th>Category</th>
<th>Elaterids</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
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<tr>
<td></td>
<td></td>
<td>Area</td>
<td>%</td>
<td>Area</td>
<td>%</td>
</tr>
<tr>
<td>2</td>
<td>Light</td>
<td>18 580.75</td>
<td>3.30</td>
<td>26 358.50</td>
<td>5.04</td>
</tr>
<tr>
<td>3</td>
<td>Medium</td>
<td>18 980.03</td>
<td>3.37</td>
<td>25 759.42</td>
<td>4.92</td>
</tr>
<tr>
<td>4</td>
<td>Intense</td>
<td>71 329.85</td>
<td>12.66</td>
<td>61 427.85</td>
<td>11.73</td>
</tr>
</tbody>
</table>

In the case of borers and rodents, a reverse behaviour is observed, the bigger contribution to damage being from borers in the stools of the spring crop of that year, which is in accordance with results that have demonstrated that the succulence of new plantings induces the proliferation of insect pests.

From the environmental standpoint, a reduction of other detrimental agents was obtained as well as the prevention of exotics, which was made possible by the application of recommendations offered by the Service for the optimum varietal composition, the evaluation of the quality of the seed used for replanting plantations, and the activation of phytosanitary awareness with all of its components.

Chemical products are not included among the recommended control practices, except in the case of rodenticides due to the little availability and stability of biological control practices under field conditions.

Conclusions

- It was defined that the main biotic factors affecting the sugarcane crop in Cuba are: smut, rust, leaf scald, borer (*D. saccharalis*) and rodents.
- It was determined that, at the national level, the incidence of the levels of smut, leaf scald, borers and rodents did not surpass the medium level, whereas the incidence of damage by rust was low.

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LE SERVICE PHYTOSANITAIRE DE LA CANNE À SUCRE À CUBA
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MOTS-CLÉS: Canne à Sucre, Lutte Contre les Nuisibles, Service Phytosanitaire.
Résumé

SERVICIO FITOSANITARIO EN LA INDUSTRIA DE LA CAÑA DE AZÚCAR EN CUBA
Por
MÉRIDA. RODRÍGUEZ, EIDA. RODRÍGUEZ, J. MATOS y M. CASAS
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PALABRAS CLAVE: Caña de Azúcar, Control De Plagas, Servicio Fitosanitario.
Resumen
Se presentan los resultados obtenidos desde 2000 hasta el presente sobre la la aplicación y la generalización del Servicio Fitosanitario (SEFIT). Este servicio ha gran tenido un impacto sobre la presencia y control de plagas y en la moderación de las pérdidas causadas por ellos en la producción de caña de azúcar. Tiene en cuenta la participación activa del capital humano inserto en el servicio, su proceso de calificación, el reconocimiento y registro de las plagas, la búsqueda de producción de semilla de calidad y el desarrollo de diferentes vínculos para obtener plantas sanas y control de las plagas. Las medidas recomendadas tienen en cuenta la biología y protección del medio ambiente. El servicio incluye una versión automatizada, único de su tipo en Cuba, que permite la toma de decisiones sobre el manejo integral de organismos nocivos y la consideración de los aspectos epidemiológicos de las cepas, las condiciones de los cultivos y cultivares comerciales. También participa en la regulación de los factores que presentan problemas fitosanitarios. Se presentan los avances en la organización de los servicios fitosanitarios en la caña de azúcar en nuestro país. Este servicio técnico y científico es ofrecido por el Instituto Nacional de Investigación de la Caña de Azúcar (INICA) y ha demostrado beneficios significativos mediante la prevención de las pérdidas de azúcar en más de 700 000 toneladas (con valor en el mercado de USD$ 216 933), debido sólo al carbón. Además, hubo otros beneficios, tales como la reducción de los índices y porcentajes de infestación por plagas, la prevención de la introducción de organismos exóticos y la reducción de las cantidades de productos de control biológico para disminuir la incidencia de plagas y enfermedades.
EVALUATION OF A REUNIONESE VARIETY INFECTED BY RATOON STUNTING DISEASE

By

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KEYWORDS: RSD, Variety,
Agronomic Evaluation, Juice Quality.

Abstract

R583 is a sugarcane variety adapted to the high altitude and dry conditions in the west part of Reunion Island. R583 is susceptible to ratoon stunting disease (RSD) caused by the bacteria Leifsonia xyli subsp. xyli (Lxx). The aim of this preliminary study was to evaluate the agronomic results and juice composition of R583 infected by RSD prior distributing the variety. Despite its susceptibility to RSD, agronomic trials have shown a 33% improvement in tonnes of sucrose per hectare compared to the widely grown variety R577. Juices from infected stalks were analysed. Differences in juice composition highlighted should not negatively affect sugar mill performance. Considering the risks of the susceptibility of R583, the improvement of sugar yield and the results of juice analysis, a decision was taken to distribute the variety with appropriate precautions.

Introduction

R583 is a variety well-adapted to high-altitude (above 500 m), dry and non-irrigated area. The current standard in this area in Reunion Island is R577. R583 is susceptible to ratoon stunting disease (RSD).

Ratoon stunting disease is a common sugarcane disease caused by a bacterium, Leifsonia xyli subsp. xyli (Lxx) located in the xylem (Gillaspie and Teakle, 1989). Because symptoms can be attributed to hydric stress, the disease can go unnoticed and can be spread inadvertently (Bailey and Bechet, 1986). Impact on cane yield is well documented (Steindl, 1961; Bailey and Bechet, 1986) but effect on juice composition with the disease is less known.

Disease evaluation of RSD is time-consuming and complex. However, it was decided to evaluate the effects of Lxx infection on the agronomic results of variety R583 in the late breeding stage and on the variety juice composition. The poster presents the results of this preliminary evaluation.

Materials and methods

Breeding field

The field trial is located in Vue-Belle station, representative of the growing area of R583. The field is composed of 5 replications of 24 varieties among which were R583 and the standard R577. It was planted on 1st March 2004. The plant crop was harvested on 25 August 2005, 1st ratoon on 23 August 2006 and 2nd ratoon on 13 September 2007.

The yield was assessed by weighing each plot. The extracted juice was analysed for pol in cane (for sucrose content), fibre and thus extractible sugar according to formulae developed at eRcane:

Fibre %Cane = 0.447 x b x 100 where b = \frac{\text{cake weight}}{\text{pulp weight}}
Extractible Sugar %Cane = Pol%g × ((1–1.24 × Fibre %Cane) × 0.9)−2
With Pol%g = Pol of Extracted juice.
Sugar content %Cane = Extractible Sugar %Cane + 2.8

**Lxx detection**

The cross section of the bottom part of cane stalks was pressed on a sheet of nitrocellulose and used to detect the pathogen in the vascular bundles by tissue blot immunoassay (TBIA) (Harrison and Davis, 1988).

**Plant material for Lxx detection**

Two series of Lxx detection were made in the breeding field trial in 2008 on the third ratoon:

1. In the first series (July 2008), 5 stalks in each plot of the breeding field trial (24 varieties, 5 replicates) were tested on seven-month old canes. The results showed that only R583 was infected by Lxx.
2. Thus, the second series made in September 2008 concerned only R583. One hundred twenty two stalks of twelve months stalks of R583 were sampled in the most infected plots. The purpose was to have as many infected stalks as possible. Then the stalks were numbered and tissue blots were made on each individual stalk.

**Juice collection**

The sampled stalks were individually crushed using a three-roller mill. For the 122 stalks, about 150 to 200 mL of extracted juice was collected and frozen for further analysis.

**Juice analysis**

In order to have sufficient juice for all analysis, juices were pooled according to their percentage of colonised vascular bundles.

Pol and brix were analysed following the non-lead method (ICUMSA Draft Method No. 9, 2007). Conductivity and pH were performed directly in raw juice with a CONSORT C532. Chromatographic analysis of sucrose, glucose, fructose, mannitol, palatinose, isomaltotriose and 1-kestose were performed using dionex high performance anionic exchange chromatography with a pulsed amperometric detector (HPAEC-PAD) following ICUMSA method (GS7/8/4-24, 1998) and with appropriate dilution.

Thirteen amino-acids were quantified using a commercial Waters AccQ.Tag Chemistry Package. Phenols were measured using the reagent Folin-Ciocalteu method (Phenolic compounds determination in cane juice, SPRI).

**Results and discussion**

**Lxx detection results**

**First series**

The first set of analyses showed that none of the stalks of R577 was infected. Presence of the Lxx occurred in 6 of the 25 stalks of R583.

**Second series (on R583)**

Lxx detection revealed that 46 of the 122 stalks (37.70%) were infected by Lxx. For infected stalks, percentage of infected vessels ranged from 3.1 to 93.9% with an average of 54.55%. As mentioned in the materials and methods, juices were pooled into groups presented in Table 1.

The first group included only juice from non-infected stalks. Seventy six of the 122 stalks were not infected by Lxx. Because the number of non-infected stalks was much higher than infected ones, it was decided to analyse only five sub-groups of 5 (total 25) of them.

Ten other groups included all the infected stalks. Range of each group is 9.1% of colonised vascular bundles. When a group is composed of 5 juices or more, two sub-groups are created to maximise the number of analyses.
Table 1—Classification of juices according to percentage of colonised vessel per stalk.

<table>
<thead>
<tr>
<th>Colonised vascular bundles (%)</th>
<th>Group mean</th>
<th>0</th>
<th>7.7</th>
<th>16.7</th>
<th>25.8</th>
<th>34.9</th>
<th>44.0</th>
<th>53.1</th>
<th>62.2</th>
<th>71.2</th>
<th>80.3</th>
<th>89.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group min.</td>
<td>-</td>
<td>3.1</td>
<td>12.2</td>
<td>21.3</td>
<td>30.4</td>
<td>39.5</td>
<td>48.5</td>
<td>57.6</td>
<td>66.7</td>
<td>75.8</td>
<td>84.9</td>
<td></td>
</tr>
<tr>
<td>Group max.</td>
<td>-</td>
<td>12.2</td>
<td>21.3</td>
<td>30.4</td>
<td>39.5</td>
<td>48.5</td>
<td>57.6</td>
<td>66.7</td>
<td>75.8</td>
<td>84.9</td>
<td>93.9</td>
<td></td>
</tr>
<tr>
<td>Sub-groups</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of stalks</td>
<td>5 5 5 5 4</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

Infected by RSD, R583 has a higher sugar yield than the healthy standard R577

In Figure 1, R583 is compared to the standard in the area of Vue Belle: R577. According to the first evaluation of RSD infection in this field (series of July), no Lxx was detected for R577; however, R583 was infected. The presented figures apply to the last stage of the breeding process for one plant crop and two ratoons. For R583, cane yield was 26.8% higher than R577 (P < 0.01), sucrose content was comparable to the standard (4.1% higher but not significant) and extractible sugar yield (cane yield × extractible sugar in cane) was 33.4% higher (P < 0.01). R583 can significantly out-yield the standard R577.

Composition of R583 juices

Linear model of each measurement versus percentage of colonised vascular bundles was performed using R software (R Development Core Team, 2009). Results of the linear model analysis presented in Table 2 details the slope of the predicted equation, the determination coefficient (R²) and the associated p-value.

No significant difference in juice was highlighted for the following measured criteria: brix, glucose, pH, phenols, kestose and 7 amino acids: aspartic acid, proline, cysteine, tyrosine, methionine, lysine and phenylalanine.

However, 15 measurements were presenting statistical differences (P value < 0.05). True purity, glucose to fructose ratio and threonine increased significantly with the percentage of colonised vascular bundles.
Significant decreases with percentage of colonised vascular bundles were associated with fructose, reducing sugar, ash, mannitol, palatinose, isomaltotriose, 5 amino-acids (glutamic acid, glycine, arginine, valine and alanine) and total amino-acids content.

**Table 2**—Effect of percentage of colonised vascular bundles on juice composition—results of linear model.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Unit</th>
<th>Slope</th>
<th>R²</th>
<th>P value significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valine</td>
<td>mg/1 kg of brix</td>
<td>-5.77E-01</td>
<td>0.56</td>
<td>0.001 **</td>
</tr>
<tr>
<td>Glucose/fructose</td>
<td>-</td>
<td>7.20E-03</td>
<td>0.51</td>
<td>0.001 **</td>
</tr>
<tr>
<td>Arginine</td>
<td>mg/1 kg of brix</td>
<td>-4.42E-01</td>
<td>0.50</td>
<td>0.002 **</td>
</tr>
<tr>
<td>Alanine</td>
<td>mg/1 kg of brix</td>
<td>-1.18E+00</td>
<td>0.46</td>
<td>0.003</td>
</tr>
<tr>
<td>Glycine</td>
<td>mg/1 kg of brix</td>
<td>-1.14E-01</td>
<td>0.41</td>
<td>0.005 **</td>
</tr>
<tr>
<td>Palatinose</td>
<td>g/100g of brix</td>
<td>-7.39E-05</td>
<td>0.40</td>
<td>0.005 **</td>
</tr>
<tr>
<td>Isomaltotriose</td>
<td>g/100g of brix</td>
<td>-4.95E-05</td>
<td>0.36</td>
<td>0.009</td>
</tr>
<tr>
<td>True purity</td>
<td>2.42E-02</td>
<td>0.34</td>
<td>0.011</td>
<td></td>
</tr>
<tr>
<td>Fructose</td>
<td>g/1008 of brix</td>
<td>-6.63E-03</td>
<td>0.30</td>
<td>0.017</td>
</tr>
<tr>
<td>Glutamic acid</td>
<td>mg/1 kg of brix</td>
<td>-1.58E-01</td>
<td>0.27</td>
<td>0.033</td>
</tr>
<tr>
<td>Total amino acids</td>
<td>mg/1 kg of brix</td>
<td>-2.32E+00</td>
<td>0.26</td>
<td>0.038</td>
</tr>
<tr>
<td>Ash</td>
<td>g/1008 of brix</td>
<td>-4.19E-03</td>
<td>0.26</td>
<td>0.032</td>
</tr>
<tr>
<td>Threonine</td>
<td>mg/1 kg of brix</td>
<td>1.14E-01</td>
<td>0.25</td>
<td>0.041</td>
</tr>
<tr>
<td>Reducing sugar</td>
<td>g/1008 of brix</td>
<td>-9.87E-03</td>
<td>0.25</td>
<td>0.036</td>
</tr>
<tr>
<td>Mannitol</td>
<td>g/1008 of brix</td>
<td>-3.06E-06</td>
<td>0.25</td>
<td>0.036</td>
</tr>
<tr>
<td>Glucose</td>
<td>g/1008 of brix</td>
<td>-3.23E-03</td>
<td>0.16</td>
<td>0.100 ns</td>
</tr>
<tr>
<td>Brix</td>
<td>g/1008 of juice</td>
<td>9.97E-03</td>
<td>0.14</td>
<td>0.131 ns</td>
</tr>
<tr>
<td>Lysine</td>
<td>mg/1 kg of brix</td>
<td>3.71 E-02</td>
<td>0.06</td>
<td>0.338 ns</td>
</tr>
<tr>
<td>Kestose</td>
<td>g/100g of brix</td>
<td>-1.15E-04</td>
<td>0.05</td>
<td>0.355 ns</td>
</tr>
<tr>
<td>pH</td>
<td>2.70E-04</td>
<td>0.05</td>
<td>0.375 ns</td>
<td></td>
</tr>
<tr>
<td>Tyrosine</td>
<td>mg/1 kg of brix</td>
<td>4.53E-03</td>
<td>0.03</td>
<td>0.512 ns</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>mg/1 kg of brix</td>
<td>-2.84E-02</td>
<td>0.03</td>
<td>0.538 ns</td>
</tr>
<tr>
<td>Proline</td>
<td>mg/1 kg of brix</td>
<td>1.93E-01</td>
<td>0.02</td>
<td>0.591 ns</td>
</tr>
<tr>
<td>Methionine</td>
<td>mg/1 kg of brix</td>
<td>-1.23E-02</td>
<td>0.02</td>
<td>0.612 ns</td>
</tr>
<tr>
<td>Phenol</td>
<td>g/1008 of brix</td>
<td>4.74E-05</td>
<td>0.02</td>
<td>0.611 ns</td>
</tr>
<tr>
<td>Cysteine</td>
<td>mg/lkg of brix</td>
<td>-1.10E-02</td>
<td>0.01</td>
<td>0.686 ns</td>
</tr>
<tr>
<td>Aspartic acid</td>
<td>mg/1 kg of brix</td>
<td>-2.26E-01</td>
<td>0.01</td>
<td>0.762 ns</td>
</tr>
</tbody>
</table>

Increase of true purity and decrease of many other components actually improves juice quality. From a sugar mill point of view, differences highlighted in this section should not affect sugar extraction. In this study, amount of most amino acids was lower when the stalk was highly infected. This had never been shown before. This might be related to the physiology of the cane once infected by Lxx.

**Conclusion**

The variety R583 is susceptible to RSD but it has a higher sucrose yield compared to the well-spread standard R577. Decrease of juice quality has not been highlighted. However, it seems that infected canes have a lower content of particular amino acids but this has not been explained so far.

In the west high-altitude dry and non-irrigated area of Reunion Island, R583 can increase growers’ income compared to the standard R577. The spreading of the disease can be controlled by thermotherapy and with appropriate precautions at harvest. Considering the risks of the
susceptibility of R583, the improvement of sugar yield and the results of juice analysis, a decision was taken to distribute the variety with appropriate precautions.

REFERENCES


ÉVALUATION D’UNE VARIÉTÉ RÉUNIONNAISE INFECTÉE PAR LA MALADIE DU RABOUGRISSEMENT DES REPOUSSES

Par

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Résumé

La R583 est une variété de canne à sucre adaptée à une altitude élevée et à des conditions sèches de l’ouest de l’île de la Réunion. La variété est sensible à la maladie du rabougrissement (RSD) causée par la bactérie Leifsonia xyli subsp xyli (Lxv). L’objectif de cette étude préliminaire consistait à évaluer les résultats agronomiques et la composition du jus de la R583 infectée par le RSD avant sa distribution. Malgré sa sensibilité au RSD, les essais agronomiques ont montré une augmentation de 33% de sucre à l’hectare en comparaison à la variété R577, largement cultivée. Le jus des cannes infectées de la R583 a été analysé et la différence dans la composition du jus ne devrait pas affecter la performance des usines. En tenant compte de la sensibilité de la R583 au RSD, de l’augmentation de rendement en sucre, et des résultats des analyses du jus, une décision a été prise de distribuer la variété en observant les précautions appropriées.
EVALUACIÓN DE UNA VARIEDAD DE REUNIÓN INFECTADA POR RAQUITISMO DE LA SOCA

Por

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PALABRAS CLAVE: RSD, Variedad, Evaluación Agronómica, Calidad de Jugo.

Resumen
R583 ES UNA variedad de caña de azúcar adaptada a condiciones de altas altitudes y clima seco, existentes en la parte oeste de la Isla de la Reunión. R583 es susceptible a la enfermedad raquitismo de la soca (RSD), causada por la bacteria Leifsonia xyli subsp xyli (Lxx). El objetivo de este estudio preliminar fue evaluar los resultados agronómicos y composición de jugos de R583 infectados por RSD, antes de la distribución de la variedad. A pesar de su susceptibilidad al RSD, los ensayos agronómicos mostraron un aumento en 33% las toneladas de azúcar por hectárea, en comparación con R577, variedad ampliamente cultivada en la Isla. Los jugos de tallos infectados fueron analizados. Las diferencias en la calidad de jugos entre sanos y afectados no afectaron negativamente la variedad en su desempeño en los ingenios azucareros. Teniendo en cuenta los riesgos de susceptibilidad de R583 pero su mayor producción de azúcar y los resultados de calidad de jugos, se tomó la decisión de distribuir la variedad, con las precauciones adecuadas.
COGENERATION POTENTIAL IN COLOMBIAN SUGAR MILLS

By
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KEYWORDS: Cogeneration, Colombia, Distillation, Electricity, Ethanol, Steam, Sugar.

Abstract
NOWADAYS, the Colombian sugar industry is involved in an expansion process, mainly related to the diversification of final products. In this way, since 2005 five ethanol distilleries are running, covering just 65% of total ethanol demand. Distilleries were designed coupled with a composting plant, based on vinasses and sludges from the sugar plant. Both distilleries and composting plants show many features which make them a special case in the ethanol market, so they produce a maximum of 3 L vinasse/L ethanol. Besides, in all cases, the thermal and electrical power requirements at the ethanol plant are supplied by the sugar plant. In this paper, a brief description of technological features of the typical process configuration followed by the Colombian sugar industry is shown. It comprises the steam consumption distribution by sections, the common configuration of the heat exchanger network (HEN) developed for vegetal steam usage and the role of the energetic self-sufficiency of the factory played by the bagasse quality. A set of possible scenarios for improving energy efficiency in a selected mill which comprises a modified HEN can be formulated, including a revamping of existing boiler and finally a new boiler operating at higher pressure. Based on the previous information, the state of the main Colombian cogeneration projects based on sugar cane and its potential impact on national energy supply is shown. Finally, the paper describes how Colombian governmental requirements for cogeneration plants are trying to establish a legal framework for this novel industrial activity in the country.

Introduction
In Colombia, the sugar sector is one of the most important thermal energy consumers. Steam % cane is an indicator of the quantity of thermal energy used in the process. This index for the Colombian sugar mills ranks between 500 and 680 kg steam/t cane. Besides, the index of electrical energy usage in the process is increasing since the ethanol plants began operation (2005), reaching values of 30 kW-h/t cane.

This paper shows how the configuration of the heat exchanger network (HEN) for different stages in the sugar mill process is useful to improve energy efficiency and to project different cogeneration configurations. Finally, as a result of this analysis, a general review of the present cogeneration projects in the sugar mills is presented, including the Equivalent Electrical Efficiency (EEE) calculated for each of them.

Methodology
First, a detailed characterisation of the production process in a selected sugar mill is required. The mass and energy balance is obtained including an evaluation of the efficiency and fuel waste in the boilers. Thus, the electrical energy generation requirement was obtained for the actual conditions.
Next, alternative cogeneration schemes for the sugar mill are projected, taking into account the implementation of new technologies for improving energy saving. After that, by applying ‘Pinch Technology’ in sections like heating, evaporation and concentration, the potential of saving steam is determined. Finally, for assessing the legal feasibility of several Colombian sugar mills’ cogeneration projects, the Equivalent Electrical Efficiency is calculated.

**Selected sugar mill characterisation**

The selected sugar mill is located in the north zone of the Cauca Valley, Colombia. The total cane crushed during 2007 was 1 260 305 tonnes for 287 working days. In Table 1, a description of principal processes used in the sugar mill is presented. The energy and mass balance for the actual scenario are presented in Figure 1.

The energy incoming with bagasse is taken by the distilleries (17.8%), the turbo generators (38.9%), the process turbines (20.4%) and the remainder is lost in the boilers. The electrical power is supplied by three turbogenerators (18.5 MW in total), which are enough to supply all process requirement. Figure 2 shows the exhaust steam use distribution in the process.

**Table 1**—Description of main features in selected sugar mill

<table>
<thead>
<tr>
<th>Section</th>
<th>Quantity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparation</td>
<td>1</td>
<td>Electrical heavy shredder</td>
</tr>
<tr>
<td>Mills</td>
<td>6</td>
<td>1 Steam power drives 5 Hydraulic power drives</td>
</tr>
<tr>
<td>Boiler</td>
<td>2</td>
<td># 1: 54446 kg/h – 22 bar – 310°C # 2: 89383 kg/h – 22 bar – 400°C</td>
</tr>
<tr>
<td>Juice heater</td>
<td>3</td>
<td>First Heater : III Effect vapour</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Second Heater: II Effect vapour</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Third Heater : I Effect vapour</td>
</tr>
<tr>
<td>Evaporation</td>
<td>5</td>
<td>Configuration of five effects</td>
</tr>
</tbody>
</table>

![Sankey diagram for the first scenario](image-url)
Options for improving energy use

First scenario: Applying HEN

The ‘Pinch Technology’ is a process designed tool which can be used in different sugar processes. So, for the selected sugar mill configuration, a new Heat Exchanger Network (HEN) would save 9 t/h exhaust steam.

In the juice heating station, a new juice heater was proposed, taking advantage of the thermodynamical quality of exhaust steam, saving around 295 kg/h of steam, by decreasing the pinch point from 12.3°C to 9°C.

The new equipment should be installed before the evaporation station. Besides, four new configurations for the juice heating station were proposed in order to save exhausted steam. In Table 2, the four alternatives are presented.

Figure 3 shows the thermal efficiency obtained by each one of these configurations. This index could be increased from 90% to 94%. The total saving in energy potential is around 9 MW.

Table 2—Possible configurations for using vapour from different effects in the juice heating station,

<table>
<thead>
<tr>
<th></th>
<th>Heater 1</th>
<th>Heater 2</th>
<th>Heater 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Configuration 1</td>
<td>III Effect vapour</td>
<td>III Effect vapour</td>
<td>I Effect vapour</td>
</tr>
<tr>
<td>Configuration 2</td>
<td>III Effect vapour</td>
<td>II Effect vapour</td>
<td>II Effect vapour</td>
</tr>
<tr>
<td>Configuration 3</td>
<td>III Effect vapour</td>
<td>III Effect vapour</td>
<td>II Effect vapour</td>
</tr>
<tr>
<td>Configuration 4</td>
<td>IV Effect vapour</td>
<td>III Effect vapour</td>
<td>II Effect vapour</td>
</tr>
</tbody>
</table>

Second scenario

For the second scenario, increasing boiler operation pressure (from 22 bar to 40 bar) and flow of cane crushed (5% more) were considered. Electrical power motors should be installed for mills and boiler fans and the use of a continuous pan using second effect vegetal vapour from the evaporation station were also considered.

Figure 4 presents this scenario layout. The modification results in saving around 2858 kg/h of steam by the use of continuous pan, and around 1.7% (2.3 MW) from the total bagasse energy is available for selling to the grid. Figure 5 presents the results.
Fig. 3—Evaporation station efficiency for proposed new configurations

Fig. 4—Modifications in the second scenario.

Fig. 5—Sankey diagram for the second scenario
Third scenario:

In this case, a new boiler operating at higher pressure and temperature (65 bar and 480°C) and a new, more efficient extraction–condensation turbo generator (5.4 kg steam / Kw-h) were considered. A 21.5 bar steam extraction is projected from the new turbo generator to supply the evaporation station. The modifications on electrification of mill station and boiler fans and continuous pan implementation from second scenario were conserved. Figure 6 shows this third scenario. In this case, electrical power available for selling to the grid reaches values of 11 MW. In Figure 7, the Sankey diagram about the energy distribution for this case is presented.

Comparisons between the total electrical power generated in each one of the three scenarios are presented in Figure 8.
General overview of colombian cogeneration sugar mill projects:

Actually, seven cogeneration projects in the Colombian sugar mills are in progress. Table 3 presents a review about the main features of them. The total potential electrical power generation is about 145 MW. Colombian governmental requirements for cogeneration plants are trying to establish a legal framework for this novel industrial activity in the country. For this purpose, an efficiency indicator was proposed, called Equivalent Electrical Efficiency (EEE), which can be determined as follow:

$$EEE = \frac{EE}{PE - \frac{UH}{\eta_{ref}}}$$

Where:
- EE = Electrical energy production
- PE = Primary Energy consumption
- UH = Useful Heat produced
- $\eta_{ref}$ = Reference Boiler Efficiency

| Table 3—Cogeneration projects in Colombian sugar mills |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| MILL # 1        | MILL # 2        | MILL # 3        | MILL # 4        | MILL # 5        | MILL # 6        | MILL # 7        |
| Cane crushed (t/h) | 440            | 300            | 270            | 370            | 330            | 580            | 230            |
| Boiler (Pressure- Temp) | 67 (bar) 540 (°C) | 67 (bar) 505 (°C) | 63 (bar) 510 (°C) | 62 (bar) 480 (°C) | 62 (bar) 480 (°C) | 45 (bar) 395 (°C) | 64 (bar) 500 (°C) |
| Turbo generator BP: Back-pressure EC : Extraction - condensation | BP (20 MW) EC (10 MW) | BP (27 MW) EC (10 MW) | BP (25 MW) | BP (20 MW) EC (20 MW) | BP (20 MW) EC (18 MW) | EC (35 MW) | BP (10 MW) EC (10 MW) |
| Power to sell | 20 (MW) | 25 (MW) | 12 (MW) | 21 (MW) | 23 (MW) | 10.5 (MW) | 10 (MW) |
| EEE - $\eta$ Ref: 90% | 23.0% | 25.4% | 27.9% | 22.6% | 22.8% | 22.2% | 23.2% |
| EEE - $\eta$ Ref: 70% | 33.4% | 37.1% | 38.4% | 33.6% | 33.8% | 35.3% | 34.0% |

So, it is proposed that a minimum value of 30% for EEE in cogeneration projects based on sugar biomass is required. For calculating EEE in any cogeneration project, reference efficiency for transformation of chemical energy of the fuel to thermal energy is necessary. The Colombian
government established 90% as a reference efficiency, but boilers using biomass fuel can just reach 70% on average. Figure 9 shows the EEE for a typical sugar mill cogeneration project calculated with 90% and 70% of reference efficiency. Predetermined EEE value of 30% is just reached using 70% of reference efficiency only.

![Graph showing EEE for cogeneration project](image)

**Conclusions**

Cogeneration is a reality for the Colombian sugar industry with seven projects, accounting for a potential sale of electric power of 145 MW, which gives it a more energetic and technological support to the sector. Planning of a cogeneration project must evaluate different scenarios, including those which involve the energy balances of the process, for determining the real potential for cogeneration. This is a vital part of the assessment of project’s feasibility. A draft of the cogeneration of steam at high temperature and high pressure will give a better chance to get the thermal energy for conversion into electricity. The use of comparative indexes for regulating cogeneration projects (as EEE in Colombian national rules) should be done in consideration of the particular conditions of the technology in use, such as in the case of bagasse boilers.
rendent particulières sur le marché de l'éthanol car elles produisent un maximum de 3 L vinasse L⁻¹ d'éthanol. En outre, l'alimentation électrique et thermique de la distillerie est fournie par les sucreries. Dans cette communication, une brève description des caractéristiques technologiques de la configuration de processus typiques de l'industrie sucrière colombienne est présentée. Cela comprend la consommation et la distribution de la vapeur par sections, la configuration du réseau échangeur de chaleur (HEN) développé pour les usages végétaux et le rôle de l'autosuffisance énergétique de l'usine assurée par la qualité de la bagasse. Un ensemble de scénarios pour améliorer l'efficacité énergétique dans une usine donnée comprend une HEN modifiée peut être formulé, y compris une réorganisation des chaudières existantes et enfin, une nouvelle chaudière fonctionnant à pression plus élevée. D'après les informations antérieures, l'état des principaux projets colombiens de cogénération à partir de la canne à sucre et son impact potentiel sur la fourniture énergétique nationale est présenté. Enfin, cette communication décrit comment le gouvernement colombien tente d'établir un cadre juridique pour cette nouvelle activité industrielle dans le pays.

POTENCIAL DE COGENERACIÓN EN INGENIOS ZUCAREROS COLOMBIANOS
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PALABRAS CLAVE: Cogeneración, Colombia, Destilación, Electricidad, Etanol, Vapor, Azúcar.

Resumen
EN LA ACTUALIDAD la industria azucarera colombiana está envuelta en un proceso de expansión, principalmente de diversificación de los productos finales. Así, desde el 2005 operan cinco (5) destilerías de etanol, que cubren solamente el 65% de la demanda total de etanol. Las destilerías fueron diseñadas acopladas a plantas de ‘compost’, basadas en vinazas y lodos residuales de las plantas de azúcar. Ambas, las destilerías y las plantas de ‘compost’, muestran muchos rasgos que las hacen un caso especial en el mercado de etanol, producen un máximo de 3L de vinazas/L de etanol. Además, en todos los casos, los requerimientos térmicos y de energía eléctrica de la planta de etanol se suministran por la planta de azúcar. En este trabajo se muestra una breve descripción de los rasgos tecnológicos de una configuración típica del proceso seguido por la industria azucarera colombiana. Esto comprende la distribución del consumo de vapor por secciones, la configuración común de la red de intercambiadores de calor (HEN), que se desarrolló para el empleo del vapor vegetal y el papel de la autosuficiencia energética que juega la calidad del bagazo... Se puede formar un juego de escenarios para incrementar la eficiencia energética en un Central seleccionado, que comprende un HEN modificado, incluyendo una reconstrucción de las calderas existentes y finalmente una caldera operando a más altas presiones... Finalmente se muestra, basándonos en la información previa, el estado de los principales proyectos colombianos de cogeneración basados en la caña de azúcar y su potencial impacto en el suministro nacional de energía. Concluyendo el trabajo con una descripción acerca del como los requerimientos gubernamentales colombianos están tratando de establecer un marco legal para esta novedosa actividad industrial en el país.
POTASSIUM REMOVAL FROM DISTILLERY SLOPS BY Candida utilis PROPAGATION

By

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KEYWORDS: Distillery Slops Decontamination, Single Cell Protein, Feed Protein, Potassium Removal.

Abstract

YEASTS accumulate varied amounts of most of the minerals present in their growth media. Much of the 7.5–8.1% ash found in the yeast grown for baking or harvested from beer is potassium phosphate, but yeast has the ability to accumulate other ions provided (but not necessarily needed) in high concentration. Distillery slops still contain about 70% of all potassium contributed to the soil in cane fields as chemical fertiliser, thus fertigation with these wastewaters has to be carefully calculated since otherwise soil salinisation can occur. When grown in a medium composed of distillery slops, nutrient salts (ammonium phosphate and sulfates) and a microbial growth enhancer Candida utilis shows a great resistance to potassium concentration in continuous culture. Yeast cells were propagated under the above conditions with increasing amounts of K2O from 2.5 g/L concentration (distillery slops from molasses fermentation) up to 25 g/L in propagation medium. Specific growth rate (µmax) ranged from 0.32 to 0.28 h⁻¹ for the extreme values mentioned above, while biomass-substrate yield coefficients were 0.23 to 0.18. These results suggest that yeast propagated on supplemented distillery slops could significantly reduce the potassium content of these wastes making them more suitable for irrigation purposes. According to the nutritional assessment reported, the potassium accumulated has no deleterious effect on animal health.

Introduction

Currently, there are 121 sugar-producing, and 57 ethanol-producing countries in the world. Roughly, 72% of the world’s sugar comes from sugarcane, and the rest from sugar beets (2005). For ethanol, 54% comes from grains, and 46% from sugarcane (2005).

Production of ethanol is concentrated mostly in Brazil and the US, which together account for 72% of world’s production in 2005. Although for decades Brazil was unrivalled as the world’s largest biomass ethanol producer, since 2005 the US has overcome Brazil as the largest producer (Nastari, 2006).

Ethanol makes an excellent motor fuel: it has a research octane number (RON) of 109 and a motor octane number (MON) of 90, both of which exceed those of gasoline. Ethanol also has a lower vapour pressure than gasoline which results in lower evaporative emission. On the other hand, anhydrous ethanol has lower and higher heating values of 21.2 mega joules per litre and 23.4 mega joules per litre, respectively; for gasoline the values are 30.1 and 34.9 mega joules per litre.

Ethanol is a fast growing source of vehicle fuel, and it is likely that it will keep on growing in the future, to be extensively blended with gasoline. Environmentalists hope it could be developed as a cleaner source of fuel than oil or natural gas.

Sugarcane agro-industry exhibits a high ecological impact in all tropical and subtropical countries that operate that production. On the other hand, it should be said that the industry
generates many jobs in the Latin American region, as sugarcane is one of the most widespread commercial plants and, at the same time, ranks among the most efficient plants with respect to bioconversion of solar energy into biomass.

Sugar and ethanol are basically the sole physical products that the sugar industry generates and both of them require large amounts of water during processing which led to the evolution of large quantities of liquid wastes (Otero et al., 2008).

Among the most polluting industrial wastes are distillery slops or vinasse from ethanol distillation, due to their content of organic and inorganic substances.

Vinasse is produced at a rate of 10 to 12 cubic metres per cubic metre of distilled ethanol unless special techniques are applied, but all they do is concentrate the same amount of BOD / COD into a smaller volume. Chemical oxygen demand in vinasse is a function of fermentation and distillation efficiencies and ranges from 30 to 85 mg/mL.

To reduce the environmental impact of vinasse disposal, several strategies have been implemented mainly through biotechnological systems in order to match current legal settings.

Among them are fertigation, anaerobic digestion, desalting and concentration, burning and recycling to reduce the amount of dilution waters (Otero et al., 2006; Otero et al., 2008).

However, the upgrading of vinasse through the production of microbial protein makes this wastewater a valuable product that in addition makes an important contribution to the sustainable management of ecosystems (Martinez et al., 2004; Otero et al., 2006).

One of the most aggressive components of vinasse is its inorganic fraction, especially potassium salts that compose the overwhelming majority of ash composition (van Haandel and van Lier, 2006).

Distillery slops still contain about 70% of all potassium contributed to the soil in cane fields, thus fertigation with these wastewaters has to be carefully calculated since otherwise salinisation is a real danger. However, at the same time, potassium is an essential ion for microbial metabolism. The assessment of the removal of potassium content from vinasse by yeast propagation is the main objective of the present paper.

Materials and methods

**Microorganism** Candida utilis NRRL Y-660 was used for propagation in all experiments. Inoculums were prepared from agar-malt slants, grown overnight in a medium at pH 4.5 containing sugarcane molasses at 20 mg/mL of total reducing sugars concentration and nutrient salts (diammonium phosphate and sulfate) to cover cell nutritional requirements using a rotary shaker at 32°C. A 2.5 L Marubishi MD5 fermenter was used to start batch propagation with a medium composed of molasses-based slops from a local distillery at a COD concentration of 60 mg/mL containing nutrient salts (see above) in the corresponding concentration to ensure that COD was the limiting substrate.

A microbial growth enhancer QZ-350 (Quimizuk, Havana, Cuba) was added to supply other micronutrients at a concentration of 0.03 mg/mL. Different amounts of potassium sulfate were added to test cell resistance and kinetic behaviour.

**Chemical analysis** nitrogen was determined according to Kjeldahl (Anon., 1983) in a 1030 Kjeltec Auto System (Tecator AB, Haganas, Sweden). Reducing sugars were estimated by copper reduction (Greenfield and Geronimus, 1985). Dry matter was done by desiccation at 105°C overnight and lipids by extraction with ethyl ether and desiccation until constant weight in a vacuum oven at 60°C.

Ash was determined by incineration at 600°C for 4 hours and referred to dry matter content. Sediment was dissolved in 1N HCl and taken up to 100 mL with distilled water; then the potassium content in ash referred to biomass dry matter was determined by atomic absorption spectrophotometry.
Results and discussion

Alcohol production from sugarcane

Distillery slops or vinasse contains organic matter as well as mineral component. Typical concentration of molasses-based vinasse is about 8–10° bx, while juice-based vinasse hardly reaches 5° bx. Table 1 shows the typical composition of both vinasses.

Table 1—Typical composition of distillery slops (vinasse) from molasses and cane juice ethanol fermentation.

<table>
<thead>
<tr>
<th>Component</th>
<th>Molasses-based</th>
<th>Juice-based</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total solids, mg/mL</td>
<td>70–80</td>
<td>25</td>
</tr>
<tr>
<td>Chemical Oxygen Demand COD, mg/mL</td>
<td>60–65</td>
<td>30–35</td>
</tr>
<tr>
<td>Biochemical Oxygen Demand (BOD) at 20ºC, mg/mL</td>
<td>48–55</td>
<td>18–20</td>
</tr>
<tr>
<td>pH</td>
<td>4.6</td>
<td>4.1–4.5</td>
</tr>
<tr>
<td>Ash, %</td>
<td>1.7–3.5</td>
<td>1.5–3.0</td>
</tr>
<tr>
<td>Nitrogen, mg/mL</td>
<td>0.70</td>
<td>0.43–0.50</td>
</tr>
<tr>
<td>Phosphorus (P2O5), mg/mL</td>
<td>0.30</td>
<td>0.25</td>
</tr>
<tr>
<td>Potassium, mg/mL</td>
<td>3.74–7.83</td>
<td>1.20–2.10</td>
</tr>
<tr>
<td>Calcium, mg/mL</td>
<td>1.8</td>
<td>0.51</td>
</tr>
<tr>
<td>Magnesium, mg/mL</td>
<td>0.77</td>
<td>0.23</td>
</tr>
</tbody>
</table>

The dominant vinasse ash component is potassium regardless of the original substrate in fermentation. This fact is a consequence of the potassium requirements of sugarcane. It is the most used nutrient and its demand by the plant can reach 800 kg/ha.

A harvest of about 100 tonnes of sugarcane removes from the soil close to 220 kg of K₂O. Around 98% of metallic ions in molasses or juices are K, Ca and Mg. In a typical molasses, potassium content in ash ranges from 70 to 75% of the whole inorganic fraction (Otero et al., 1993).

The use of vinasse for soil fertilisation has evolved from the direct disposal to water streams in the 1970s to the current rational utilisation as fertiliser that prevents, or at least tries to, underground water contamination (Veronez de Sousa, 2008).

However, it has been documented that the main disadvantage of vinasse fertigation lies in the distance from its site of generation to the field. When that distance reaches 50 km, the real cost for irrigation increases far beyond 300 US dollars/ha.

Thus, the area of current disposal of vinasse for this purpose is normally significantly smaller than the original area where cane was harvested with the concomitant accumulation of unused potassium in the soil.

Potassium ions are the most abundant intracellular cations in most types of cells, from yeast to humans. Potassium has been reported to play a crucial role in a variety of cellular processes, including regulation of cell volume, intracellular pH, and protein synthesis, plus the prevention of the deleterious effects of sodium ions (Gomez et al., 1996; Rodriguez-Navarro, 2000; Camacho et al., 2005). Even more, during potassium limitation, ammonium ions become toxic for yeast metabolism (Hess et al., 2006).

The propagation of yeast on vinasse is capable of removing potassium from the growth medium and embodying it in the cell biomass. In doing so, a potentially valuable protein source is also produced.

To assess the inhibition limits of potassium in yeast growth, a set of experiments under different potassium concentrations was done. Table 2 shows yeast kinetic parameters at different potassium concentrations.
Table 2—Growth parameters of *Candida utilis* NRRL Y-660 under different potassium concentrations.

<table>
<thead>
<tr>
<th>[K⁺], mg/mL</th>
<th>μmax, h⁻¹</th>
<th>P, mg/mL–h</th>
<th>Yx/s</th>
<th>K in yeast, mg/mL</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00*</td>
<td>0.228</td>
<td>1.403</td>
<td>0.226</td>
<td>21.2</td>
</tr>
<tr>
<td>12.96</td>
<td>0.225</td>
<td>1.321</td>
<td>0.206</td>
<td>32.7</td>
</tr>
<tr>
<td>25.91</td>
<td>0.175</td>
<td>1.236</td>
<td>0.177</td>
<td>42.1</td>
</tr>
</tbody>
</table>

*K⁺ = 5 mg/mL

The table shows the kinetic behaviour of yeast cells under K⁺ concentration between 5 and 30 mg/mL. This concentration is far beyond the normal content in vinasse. Up to 13 mg/mL, there is no significant effect of potassium concentration on specific growth rate, productivity or biomass-substrate yield for *C. utilis*.

The values for μmax are quite similar to those previously reported by the authors of the present paper (Martinez *et al.*, 2004; Otero *et al.*, 2008) for the same medium without potassium addition.

The fact that yeast is capable of growth in high potassium concentration is important but not enough for vinasse decontamination. Yeasts accumulate varied amounts of most of the minerals present in their growth media and have the ability to accumulate other ions provided (but not necessarily needed) in high concentration.

Therefore, the mineral content of cells harvested from a particular propagation medium could be adjusted to be of significance for the removal of undesirable metals in liquid wastes (Duncan *et al.*, 1995; Otero *et al.*, 2000). The last column in Table 2 shows the potassium content accumulated in yeast cells under the different experimental conditions.

In standard vinasse, yeasts remove about 50% of the potassium present in the growth medium. As potassium content in the propagation broth increases, the amount of potassium removed by yeast cells also increases but in a lesser proportion with respect to the amount provided. However, for all practical purposes yeast propagation not only reduces the organic load of vinasse by 60–70% (Otero *et al.*, 2007) but also half of its potassium content.

Reports about vinasse-yeast use in animal nutrition showed no deleterious effect on animal health (Lezcano and Mora, 2008; Llanes-Iglesias *et al.*, 2008; Rodriguez *et al.*, 2008).

**Conclusions**

Yeast propagation offers a unique method for vinasse decontamination, reducing both the organic fraction and the potassium content to a significant extent. According to the results presented above, the propagation of yeast on vinasse medium is an excellent pretreatment for further irrigation. Vinasse with less than 30 mg/mL of COD and potassium content below 2.5 mg/mL offers no ecological impact when used for irrigation of cane fields.

**REFERENCES**


ELIMINATION DU POTASSIUM DES VINASSES DE DISTILLERIE AU MOYEN DE CANDIDA UTILIS

Par

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MOTS-CLÉS: Décontamination des Vinasses de Distillerie,
Protéines Unicellulaire, Protéines d’Alimentation, Suppression de Potassium.

Résumé

LES LEVURES sont connues pour accumuler des montants variés de la plupart des minéraux présents dans leurs milieux de culture. La majeur partie de 7.5-8.1 % de cendres trouvée dans la levure boulangère ou de brasserie est composée de phosphate de potassium, mais les levures ont le moyen d'accumuler d'autres ions qui s'y trouvent en concentration élevée, mais ces ions ce sont pas nécessairement requis. La vinasse de distillerie contient encore environ 70 % de potassium provenant des engrais chimiques utilisés dans les champs de canne à sucre d'où la nécessité d'utiliser ces rejets par fertigation avec précaution afin d'éviter des problèmes de salinité. Lorsqu'elle est cultivée dans un milieu composé de vinasse de distillerie, éléments nutritifs tels (phosphates et sulfates d'ammonium) et un promoteur de croissance, Candida utilis montre une grande résistance à la concentration de potassium en milieu de culture continue. Des cellules de cette levure ont été propagées dans les conditions sus-mentionnées avec des concentration de K2O variant de 2.5 g/L à 25 g/L en prevenance de la vinasse résultant de la fermentation de mélasse. Des taux de croissance spécifique (μmax) allant de 0.32 à 0.28 h⁻¹ pour les valeurs extrêmes sus-mentionnées ont été obtenus, alors que les coefficients de rendement de la biomasse-substrat étaient 0.23 à 0.18. Ces résultats suggèrent que la levure propagée sur des vinasses de distillerie enrichies peut réduire considérablement la teneur en potasse de ces rejets en les rendant plus aptes à des fins d'irrigation. Selon l'évaluation nutritionnelle qui est rapportée, le potassium accumulé n'a aucun effet nuisible sur la santé animale.
REMOCIÓN DEL POTASIO DE LOS RESIDUALES DE LA DESTILACIÓN MEDIANTE LA PROPAGACIÓN DE CANDIDA UTILIS.

Por

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PALABRAS CLAVE: Decontaminación, Residuales de Destilería,
Proteína Unicelular, Proteína Alimenticia, Remoción De Potasio.

Resumen

LAS LEVADURAS acumulan diferentes cantidades de la mayoría de los minerales presentes en sus medios de cultivo. La mayor parte del 7,5-8,1% de cenizas encontradas en la levadura de panificación ó cultivada para cervaza está constituida por fosfato de potasio, pero las levaduras tienen la habilidad de acumular, en altas concentraciones otros iones suministrados (pero no requeridos). Los residuales de destilerías contienen todavía cerca del 70% del potasio que se aporta a los suelos cañeros como fertilizante químico, de aquí que la fertirrigación con estas aguas residuales debe ser cuidadosamente calculada, porque de lo contrario puede producirse salinización del suelo. La Candida utilis cuando es cultivada con técnicas de fermentación continua en un medio compuesto por residuales de destilería, sales nutrientes (fosfatos y sulfatos de potasio)y un estimulador del crecimiento microbial, muestra una alta resistencia a las concentraciones de potasio. Se propagaron células de levadura, bajo las condiciones anteriormente descritas, con cantidades crecientes de óxido de potasio desde 2.5g/L (residuales de destilerías que emplean melazas) hasta 25 g/L en los medios de cultivo. La velocidad específica de crecimiento (µ max) osciló entre 0.32 y 0,28 h⁻¹ para los valores extremos referidos anteriormente, obteniéndose también coeficientes de rendimiento biomasa-sustrato de 0.23 a 0.18. Estos resultados sugieren que levaduras propagadas en residuales de destilerías suplementados, pueden reducir significativamente el contenido de potasio de estos residuales, haciéndolos más apropiados para la irrigación. De acuerdo con los resultados nutricionales reportados , el potasio acumulado no tiene ningún efecto negativo en al salud animal.
COMMUNITIES AUTO SUFFICIENT IN FUELS FOR HUMANS, TRANSPORT AND ELECTRIC NEEDS

By

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KEYWORDS: Sugar, Ethanol, Co-generation.

Abstract

In view of the present problems facing the world with respect to fossil fuels (pollution and global warming, availability and price), we studied the possibility of a small community becoming auto sufficient in sugar, automotive fuel (ethanol) and electricity, all from renewable biomass (sugarcane). The study was done, based on a real project that we are presently installing under similar lines. The fuel needs of a community of 100,000 people were quantified in terms of sugar, ethanol, and electricity. A mass and energy balance was calculated to determine the amounts of cane and trash needed to produce the sugar, ethanol and electricity by generation and co-generation. The results showed us that 100 tonnes of cane per hour can supply sufficient sugar and electric energy for a community of 100,000 people and run their cars on 96ºGL ethanol (no mix with gasoline) and still be able to export surplus ethanol. The auto sufficiency is for the whole year and not only the crop period. The overall results showed us that, when compared to the importation of ‘fuels’, the project was positive.

Introduction

The aim of this paper is to show how a relatively small sugar and ethanol factory with cogeneration (and straight generation) can provide all of the energy necessary to ‘fuel’ small communities with:

- Human fuel: sugar.
- Transport fuel: ethanol.
- Lighting and heating fuel: electricity.

The idea is to produce sugar and ethanol from mixed juice from sugarcane. The resulting molasses from the sugar production would go to ethanol production. To produce the electrical energy, we would burn all the bagasse and a part of the cane trash in a high pressure boiler.

To have electrical energy all year round (crop and off-crop), we will show that we can divide the bagasse and trash for crop and off-crop generation.

Communities

To establish the amounts of ‘energies’ needed by the community, we have made the following assumptions in Table 1:

<table>
<thead>
<tr>
<th>Energy</th>
<th>Specific Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar</td>
<td>30 kg per person per year</td>
</tr>
<tr>
<td>Ethanol</td>
<td>1200 litres per vehicle per year</td>
</tr>
<tr>
<td>Electrical energy</td>
<td>200 kWh per home per month</td>
</tr>
</tbody>
</table>
If we assume a community of 100 000 people, and that, on average, there will be one house for every 4 people and 1 vehicle for every house, Table 2 shows the annual quantities:

**Table 2**—Annual quantities required.

<table>
<thead>
<tr>
<th>Energy</th>
<th>Annual quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar</td>
<td>30 kg x 100 000 = 3000 tonnes sugar</td>
</tr>
<tr>
<td>Ethanol</td>
<td>25 000 vehicles x 1200 = 30 000 000 L</td>
</tr>
<tr>
<td>Electrical energy</td>
<td>25 000 homes x 200 x 12 = 60 000 MWh</td>
</tr>
</tbody>
</table>

The electricity is the equivalent of ~ 6.9 MW.

**Field and factory**

To be able to take advantage of the trash, the cane cannot be burnt. The cane has to be machine harvested and a part be sent to the factory with the cane. This can be controlled by fans on the harvesters. The tops which will almost surely be green should be left in the field.

The amount of trash sent to the factory should be about 10% of the (clean) cane. That means that a fair amount of trash will still remain on the fields, which is good from the agronomic point of view.

At the factory, a cane/trash separation system must be used on the feed table or preferably on a carrier. The trash is separated by fans, when the cane falls from one carrier to another.

The separated trash will then be cleaned of its dirt (soil and sand) in a dry cleaning system (rotary screen). After cleaning, it must be shredded and sent to join the bagasse at the outlet of the mill.

Ideally, for high extraction and low maintenance costs, a diffuser would be better than mills.

The mixed juice is divided into two streams, one for sugar and the other for ethanol. The amounts of juice for each stream will of course depend on the amounts of sugar and ethanol to be produced.

Ideally, one of the streams would be preset and the other would receive the balance. The quantities for this specific project can be seen on Figure 2.

Preparation of the juice to be used for sugar production will be relatively conventional: clarifier and multiple effect evaporators.

As the amount of muds will be very small, they can be recycled to the diffuser, thus eliminating the filter station, and its associated losses.

In the boiling house, we will use just one boiling as the amount of sugar required will be very small as opposed to ethanol.

This gives us the added advantage of being able to make a very good quality sugar (raw or mill white) as there are no molasses boilings.

We will have a purity drop of about 15 points. All the molasses will go to the distillery with a purity of about 70º.

The second mixed juice stream will go directly to the fermentation without needing clarification. It has, however, to be well screened and heated and then cooled on arriving at the distillery. Diffuser juice is clean enough for fermentation.

Fermentation will take place with a mixture of juice and molasses. The fermented juice ‘must’ (beer/wine) will go on to the distillery where hydrous (96ºGL) ethanol will be produced.

Figure 1 shows the basic flow diagram of the plant.
The bagasse that leaves the mill after the diffuser receives the trash and then goes on to the boiler. At this point, part of the ‘fuel’ (bagasse + trash) can be divided, part being burnt and part stocked for off-crop generation, or all can be burnt, thus generating more energy, but only during the crop.

A high pressure boiler must be used. For this simulation, we are considering a 65 bar pressure and superheated steam temperature of 480°C on arrival at the turbine.

In the case of burning all the fuel, a steam turbine with an exhaust extraction for process and an extraction direct to a condenser can be used. If generation is to be all year round, it would be preferable to have 2 turbines: a back pressure turbine and a condensing turbine.

If we consider:
- live steam at 65 bar and 480°C
- exhaust steam at 2.5 bar
- condenser steam at 0.1 bar

The specific steam consumption will be as follows in Table 3.

<table>
<thead>
<tr>
<th>Steam</th>
<th>Specific steam consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exhaust steam</td>
<td>From 65 bar To 2.5 bar Kg steam/kWh 5.4</td>
</tr>
<tr>
<td>Condenser steam</td>
<td>From 65 bar To 0.1 bar Kg steam/kWh 3.9</td>
</tr>
</tbody>
</table>
The plant will be totally electric. This fact plus the amount of water needed for the TG condenser, its cooling and the energy needed for the trash treatment will give us an electric energy consumption above that of a conventional steam driven factory.

**Balances**

Below are 3 balances (Figures 2, 3 and 4). In Figures 2 and 3 we have used a maximum of 500 kg process steam per tonne cane.

In fact, we know that this figure can come down to the range of 350 to 450, depending on what steam economy techniques are used.

The process steam consumers are the evaporation, diffusion and distillation and boiling. Distillation and boiling can be done with bleeding of first and second vapours. Primary heating of water and or juice can be done with vinasse.

Figure 2 shows a flow diagram and balance of a 100 tch plant burning all its fuel during the crop:

![Diagram showing mass and energy balance](image)

**Fig. 2**—Mass and energy balance of plant burning all its fuel during the crop period.

Figure 3 shows a flow diagram and balance of a 100 tch plant burning the amount of bagasse it needs to generate the steam necessary for the process during the crop, plus a small additional amount to reach the energy export necessity.
Figure 3—Mass and energy balance of plant burning part of its fuel during the crop period.

Figure 4 shows a flow diagram and balance of the same 100 tch plant, during the off-crop, burning the fuel left over from the crop.

It must be remembered that our fuel is bagasse and trash. During the crop, the trash is mixed into the bagasse before it is either burned or stocked.

Therefore, we can assume that during the off crop we will be burning a mixture of bagasse and trash.

It can be seen that the amount of bagasse burnt per hour is less than what was burnt per hour during the crop, but the amount of exportable energy is more.

This is because all the steam goes directly down to condenser pressure (0.1 bar) and thus has a higher enthalpy drop. In this case, we have pure thermo electric generation and not co-generation.

Thus, even though the crop harvest lasts only six months, we are able to generate electricity all year round and in the same quantity.

The overall scheme, operating throughout the year, therefore, produces as presented in Table 4.

**Table 4—Yearly production.**

<table>
<thead>
<tr>
<th>Product</th>
<th>Production Necessity Extra</th>
<th>Sugar tonnes</th>
<th>Ethanol m^3</th>
<th>Electricity MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar tonnes</td>
<td>3742</td>
<td>3000</td>
<td>742</td>
<td>19.83%</td>
</tr>
<tr>
<td>Ethanol m^3</td>
<td>35 492</td>
<td>30 000</td>
<td>5492</td>
<td>15.47%</td>
</tr>
<tr>
<td>Electricity MW</td>
<td>7.00</td>
<td>6.90</td>
<td>0.10</td>
<td>1.43%</td>
</tr>
</tbody>
</table>
Fig. 4—Mass and energy balance of plant burning its stocked fuel during the off-crop period.

It can be seen that we have a 19% excess of sugar and a 14% excess of ethanol. These products can be exported or sold to hotels, hospitals etc.

From these figures, we can now draw up a Table for various sizes of communities (Table 5).

<table>
<thead>
<tr>
<th>Cane</th>
<th>Population</th>
<th>Houses</th>
<th>Vehicles</th>
<th>Sugar</th>
<th>Ethanol</th>
<th>Electricity</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCD</td>
<td>TCH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 200</td>
<td>50</td>
<td>50 000</td>
<td>12 500</td>
<td>12 500</td>
<td>1871</td>
<td>17 746</td>
</tr>
<tr>
<td>2 400</td>
<td>100</td>
<td>100 000</td>
<td>25 000</td>
<td>25 000</td>
<td>3742</td>
<td>35 492</td>
</tr>
<tr>
<td>3 600</td>
<td>150</td>
<td>150 000</td>
<td>37 500</td>
<td>37 500</td>
<td>5613</td>
<td>53 239</td>
</tr>
<tr>
<td>4 800</td>
<td>200</td>
<td>200 000</td>
<td>50 000</td>
<td>50 000</td>
<td>7484</td>
<td>70 985</td>
</tr>
<tr>
<td>6 000</td>
<td>250</td>
<td>250 000</td>
<td>62 500</td>
<td>62 500</td>
<td>9355</td>
<td>88 731</td>
</tr>
<tr>
<td>7 200</td>
<td>300</td>
<td>300 000</td>
<td>75 000</td>
<td>75 000</td>
<td>11 226</td>
<td>106 477</td>
</tr>
<tr>
<td>8 400</td>
<td>350</td>
<td>350 000</td>
<td>87 500</td>
<td>87 500</td>
<td>13 097</td>
<td>124 224</td>
</tr>
<tr>
<td>9 600</td>
<td>400</td>
<td>400 000</td>
<td>100 000</td>
<td>100 000</td>
<td>14 968</td>
<td>141 970</td>
</tr>
<tr>
<td>10 800</td>
<td>450</td>
<td>450 000</td>
<td>112 500</td>
<td>112 500</td>
<td>16 839</td>
<td>159 716</td>
</tr>
<tr>
<td>12 000</td>
<td>500</td>
<td>500 000</td>
<td>125 000</td>
<td>125 000</td>
<td>18 710</td>
<td>177 462</td>
</tr>
</tbody>
</table>
Conclusion

We have shown two possible scenarios:

- Producing sugar, ethanol and electric energy burning all the fuel (bagasse and trash).
  
  This option would be ideal in places where it is possible to run the plant all year round. An example of this is Peru where, in the absence of rain, they are obliged to irrigate in desert lands. The advantage is that they can operate all year round.

- Producing sugar, ethanol and electric energy burning only part of the fuel during the crop, and the rest during the off crop to continue electric energy production.

  In this case, the exportable electric energy production is about half of that in the first case, but over a longer period [assuming a six month harvest season].

  If we assume an agricultural productivity of 80 tonnes cane per hectare and a harvest period of 180 days, it would be necessary to have:
  
  \[
  100 \times 24 \times 180 = 432\ 000 \text{ tonnes cane}
  \]
  
  \[
  432\ 000 / 80 = 5400 \text{ ha}
  \]

  Assuming a plant crop and 4 ratoons, we need to increase the land by 20%: 6480 ha

  Therefore, with 6480 ha of land and sufficient rainfall, it is possible to supply a community of 100 000 with all their sugar, electricity and automotive fuel (pure hydrous ethanol with no gasoline mixture)

  This industry would create jobs (factory and field) and still save money on imported fuel (oil/gasoline/diesel). This money could be recirculated within the community or used for importation on other needed goods.

  An estimated cost of such an industry of this size (100 tonnes cane/hour) is US$70 000 000 installed. The cost of the field side would depend on other non technical factors, but we could say its cost would be similar to that of the factory. Therefore, such an agro-industry could be implemented for about US$140 000 000.

  Many small countries/islands spend this or more per year importing oil. At US$100/barrel, this is equivalent to a consumption of about 4000 barrels per day.

  Perhaps on a medium to long-term basis the most important message here is that:

  **MOST OR ALL THE CO₂ PRODUCED IS RECYCLED.**
COMMUNAUTÉS AUTOSUFFISANT EN CARBURANT POUR LES BESOINS DE L’HOMME, LE TRANSPORT ET L’ÉNERGIE ÉLECTRIQUE

Par

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MOTS-CLÉS: Sucre, éthanol, Co-generation.

Résumé
COMPTÉ tenu des problèmes actuels auxquels le monde fait face par rapport à des combustibles fossiles (la pollution et le réchauffement planétaire, disponibilité et prix), nous avons étudié la possibilité qu’une petite communauté devienne autosuffisante en sucre, en carburant automobile (éthanol) et en électricité, cela à partir de la biomasse renouvelable (la canne à sucre). L’étude faite, a été basée sur un véritable projet que nous mettons en route actuellement dans un cas similaire. Les besoins en carburant d'une communauté de 100 000 personnes ont été quantifiés en termes de sucre, d'éthanol et d'électricité. Un bilan de masse et de l'énergie a été calculé pour déterminer la quantité de canne à sucre et de pailles nécessaire pour produire le sucre, l'éthanol et l'électricité par cogénération. Les résultats ont démontré que 100 tonnes de canne par heure peuvent fournir suffisamment de sucre et de l'énergie électrique pour une communauté de 100 000 personnes et rouler leurs voitures entièrement sur l’éthanol et de surcroît être en mesure d'exporter un surplus d'éthanol. L’autosuffisance est pour l'ensemble de l'année et pas seulement pendant la période de récolte. Les résultats ont démontré que, par rapport à l'importation de "combustibles", le projet a été positif.

COMUNIDADES AUTO SUFICIENTES EN COMBUSTIBLES PARA LAS NECESIDADES HUMANAS, DE TRANSPORTE Y ELÉCTRICAS

Por

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PALABRAS CLAVE: Azúcar, Etanol, Cogeneración.

Resumen
EN VISTA de los presentes problemas que el mundo enfrenta en relación con los combustibles fósiles contaminación y calentamiento global, disponibilidad y precios) estudiamos la posibilidad de una pequeña comunidad convertida en autosuficiente en azúcar, combustible automotor (etanol) y electricidad, todo a partir de la biomasa renovable (caña de azúcar). El estudio se realizó en un proyecto real que estamos instalando actualmente bajo similares líneas. El combustible necesario para una comunidad de 100 000 personas se cuantificaron en términos de azúcar, etanol y electricidad. Se calculó un balance de masa y energía para determinar las cantidades de caña y paja necesarias para producir el azúcar, el etanol y la electricidad por generación. Los resultados nos mostraron que 100 toneladas métricas de caña por hora puede suministrar suficiente azúcar y energía eléctrica para una comunidad de 100 000 personas y abastecer sus autos con etanol (sin mezcla) y aún ser capaces de exportar etanol sobreante. La autosuficiencia es para un año completo y no solo para el periodo de zafra. Los resultados totales nos mostraron que cuando se compara con la importación de combustibles era positivo.
IMPROVING PRODUCTIVITY IN SUGAR MILLS BY INTEGRATING CO-PRODUCTS UTILISATION

By

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²Coordinador of Periferical Bussines
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Abstract

This paper shows an ‘incentive program’ for workers, through one model of development, using mainly co-products of sugarcane; used in different ways in ‘Granja Teresita’, 25 kilometres from the mill. The mill has a plant to hydrolyse bagasse in two batch reactors by a physical process (using steam at 1.4 MPa) and areas for composting residuals (90 days, without enzymatic process), and sell the production to the ranch. For cattle and goats, we use the cane tops with molasses, hydrolysed bagasse, wet fibre cane ‘cush – cush’ separated in clarifier filters, and other agriculture residuals of the region. For pigs, invert ‘B’ molasses and some locally produced complements are used. For sustainable agriculture, organic fertiliser (compost), made from sugar mill products (vacuum filter mud, bagasse, ashes, etc), and worm compost, produced locally, are used with lamb manure. A range of crops is grown including corn and sorghum and horticultural crops, and there is also an aquaculture industry.

Introduction

In order to increase the productivity in the MOTZORONGO sugar group, which includes two mills (El Refugio (syrup) and Motzorongo (sugar & molasses)), the administration has promoted a program based on compensation of workers, giving a box that includes several products obtained by cane diversification processes, with several agro-products which are shown in Figure 1.

Fig. 1—Co-products development into the mills.
Work development

El Refugio Mill

Hydrolysed bagasse production

In the El Refugio Mill, there are two reactors (1.5 m diameter and 4 m high – see Figure 2) fed for 40 min with steam at 1.7 MPa and 573 K; the nominal capacity of each is 750 kg per batch. The total capacity of the plant is 2000 tonnes per crop. The composition of hydrolysed bagasse is presented in Table 1.

![Bagasse hydrolysed reactors](image)

**Fig. 2**—Bagasse hydrolysed reactors.

<table>
<thead>
<tr>
<th>Analysis of hydrolysed bagasse.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humidity</td>
</tr>
<tr>
<td>Dry matter</td>
</tr>
<tr>
<td>Phosphorus</td>
</tr>
<tr>
<td>Ashes</td>
</tr>
<tr>
<td>Crude protein</td>
</tr>
<tr>
<td>Crude fibre</td>
</tr>
<tr>
<td>Crude grease</td>
</tr>
</tbody>
</table>

Central Motzorongo, S.A. de C.V.

The mill is dedicated to the production of raw and standard sugar, with a daily grinding capacity of 8500 tonnes of cane and a total crop of 1 280 000 tonnes. The co-products produced are shown in Figure 3.
Compost

The production of organic fertiliser ‘compost’ is 3000 tonnes, using 20 000 t of filter mud and 4500 t of bagasse. The materials are sent to special areas forming long piles, and are maintained for 15 days to separate the excess water; after that, the components are mixed weekly and air is introduced for the micro organisms that degrade the organic material (fungus and bacteria) (Figure 4). The chemical composition of the compost is presented in Table 2.

Table 2—Chemical composition of ‘COMPOMOTZ’:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>2.50%</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0.60%</td>
</tr>
<tr>
<td>Potassium</td>
<td>1.20%</td>
</tr>
<tr>
<td>Calcium</td>
<td>1.40%</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.24%</td>
</tr>
<tr>
<td>Iron</td>
<td>1.20%</td>
</tr>
<tr>
<td>Organic Mater</td>
<td>54%</td>
</tr>
<tr>
<td>Acids. Humic &amp; fulvics</td>
<td>2%</td>
</tr>
<tr>
<td>pH</td>
<td>6.8</td>
</tr>
<tr>
<td>C/N Relationship</td>
<td>12:1</td>
</tr>
<tr>
<td>Humidity</td>
<td>20–30 %</td>
</tr>
</tbody>
</table>

Teresita farm

The farm is located about 25 km from El Refugio, and has a total area of 112 ha; 20 ha for sugarcane, leaving the remaining 92 ha for cattle and fruit production, including 3.50 ha for banana.
(musa ssp), mango (manguifera indica L), and noni (morinda citrifolia) and 2.50 ha for short-cycle vegetables. The other 86 ha are used as pasture and corrals for cattle and sheep, fish tanks and pig breeding places. The farm buys molasses and compost from Motzorongo, hydrolysed bagasse and mud from El Refugio (it only pays the freight of the last) and sells the products to both mills. A flow chart of the incentive program is presented in Figure 5.

![Flow chart of the incentive program.](image)

**Cattle food**
To make balanced diets for the animals, sugarcane (juice and tops) and co-products from the milling process (molasses, hydrolysed bagasse and dry filter mud), as well as cheese whey and other products from the regional agriculture are used.

**Cattle**
Grazing is the basic feed, complemented with sugarcane co-products. The cattle are classified as milking cows, empty cows, calves, and stud bulls.

**Milking cows**
They are given a supplement of 5 kg of concentrate after milking to complement their feed from grazing. The production cost per litre is no more than $1.50 (feeding) and it is sold for $7.00/L. With this regime, there is a reduction from 220 to 120 days from giving birth to getting pregnant again. This way, the productive and reproductive parameters are higher. The composition of food for milking cows is shown in Table 3.

**Table 3—Components for a tonne of food for milking cows.**

<table>
<thead>
<tr>
<th>InputS</th>
<th>Quantity</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane tops</td>
<td>20% 200</td>
<td>100.00</td>
</tr>
<tr>
<td>Hydrolysed Bagasse</td>
<td>50% 500</td>
<td>200.00</td>
</tr>
<tr>
<td>Molasses</td>
<td>17% 170</td>
<td>170.00</td>
</tr>
<tr>
<td>Crushed corn</td>
<td>8% 80</td>
<td>280.00</td>
</tr>
<tr>
<td>Urea</td>
<td>3% 30</td>
<td>135.00</td>
</tr>
<tr>
<td>Dry filter mud</td>
<td>2% 20</td>
<td>5.00</td>
</tr>
<tr>
<td><strong>TOTAL COST</strong></td>
<td><strong>$890.00 – US$65.93</strong></td>
<td></td>
</tr>
<tr>
<td><strong>COST / kg</strong></td>
<td><strong>$0.89 – US$0.07</strong></td>
<td></td>
</tr>
</tbody>
</table>

**NOTE:** Exchange rate used is $13.50 Mexican Pesos/US$dollar.
The cost of sugarcane is only for manpower. The cost of feeding each cow is $4.45 per day. The cows given this supplement increased their milk production by 3 L/day. That is a daily gain of $21.00.

**Empty cows**

These are cows that are pregnant or empty in preparation to enter into the milk production of the farm. Composition of the supplement given to empty cows is presented in Table 4.

**Table 4**—Ingredients of a tonne of food for empty cows.

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Quantity</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molasses</td>
<td>96</td>
<td>960.00</td>
</tr>
<tr>
<td>Dry mud</td>
<td>2</td>
<td>5.00</td>
</tr>
<tr>
<td>Urea</td>
<td>2</td>
<td>90.00</td>
</tr>
<tr>
<td><strong>Total cost</strong></td>
<td></td>
<td><strong>$1055.00 U$78.15</strong></td>
</tr>
<tr>
<td><strong>Cost / kg</strong></td>
<td></td>
<td><strong>$1.06 – U$ 0.08</strong></td>
</tr>
</tbody>
</table>

The daily cost for feeding one cow is $5.30.

**Calves**

It is more expensive to nurse a calf with only its mother’s milk than to give food as a supplement; with it, the milk feeding can be reduced up to 50%. The composition of the supplement for calves is shown in Table 5.

**Table 5**—Ingredients for a tonne of food for calves.

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Quantity</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrolysed bagasse</td>
<td>65</td>
<td>260.00</td>
</tr>
<tr>
<td>Molasses</td>
<td>20</td>
<td>200.00</td>
</tr>
<tr>
<td>Dry filter mud</td>
<td>2</td>
<td>5.00</td>
</tr>
<tr>
<td>Crushed corn</td>
<td>6</td>
<td>210.00</td>
</tr>
<tr>
<td>Soybean and blood meal</td>
<td>5</td>
<td>350.00</td>
</tr>
<tr>
<td>Urea</td>
<td>2</td>
<td>90.00</td>
</tr>
<tr>
<td><strong>Total cost</strong></td>
<td></td>
<td><strong>$1115.00 – U$ 82.59</strong></td>
</tr>
<tr>
<td><strong>Cost / kg</strong></td>
<td></td>
<td><strong>$1.12 – U$ 0.08</strong></td>
</tr>
</tbody>
</table>

Feeding them only with milk will cost $28.00 daily to gain 1 kg of weight; using a diet of 2 L of milk plus 2 kg of supplement will cost $16.24 per day.

**Sheep**

Their feeding should be by grazing, but seeking the highest rate of reproduction, it is convenient to give supplement and chopped sugarcane with urea, which produces good results at low cost. The ingredients in the supplement for sheep are presented in Table 6.

**Table 6**—Ingredients for a tonne of food for sheep.

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Quantity</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bagasse</td>
<td>87</td>
<td>261.00</td>
</tr>
<tr>
<td>Molasses</td>
<td>10</td>
<td>100.00</td>
</tr>
<tr>
<td>Urea</td>
<td>3</td>
<td>35.00</td>
</tr>
<tr>
<td><strong>Total cost</strong></td>
<td></td>
<td><strong>$ 396.00 – u$ 29.33</strong></td>
</tr>
<tr>
<td><strong>COST / kg</strong></td>
<td></td>
<td><strong>$ 0.40 – U$ 0.03</strong></td>
</tr>
</tbody>
</table>

This bagasse is the one that remains after the juice extraction process that is also used to feed the sheep. The price of this is calculated as $0.30 pesos, which is the milling cost.
Pigs

To prepare the diets for pigs, cane juice, cheese whey from the farm and a concentrated feeding supplement are used. The composition of the supplement given to feeding sows and breeding stud is given in Table 7.

Table 7—Ingredients of the ration for sows just after giving birth and breeding stud.

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Content</th>
<th>kg of inputs</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheese whey</td>
<td>43.75%</td>
<td>3.5</td>
<td>1.05</td>
</tr>
<tr>
<td>Cane juice</td>
<td>43.75%</td>
<td>3.5</td>
<td>2.45</td>
</tr>
<tr>
<td>Concentrate</td>
<td>12.5%</td>
<td>1.0</td>
<td>4.50</td>
</tr>
<tr>
<td><strong>Total Cost of the ration (daily consumption per animal)</strong></td>
<td></td>
<td></td>
<td>$ 8.00 – U$ 0.59</td>
</tr>
</tbody>
</table>

This ration is given to the pig for the first 25 days. Feeding with the traditional diet costs $27.00 (6 kg per day) and, with the use of byproducts, we lower the cost to $8.00, which represents a saving of $19.00 per animal.

Pregnant sows

The composition of the supplement for pregnant sows is given in Table 8.

Table 8—Supplement for pregnant sows.

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Content</th>
<th>kg of inputs</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheese whey</td>
<td>43.75%</td>
<td>3.5</td>
<td>1.05</td>
</tr>
<tr>
<td>Cane juice</td>
<td>31.25%</td>
<td>2.5</td>
<td>1.75</td>
</tr>
<tr>
<td>Concentrate</td>
<td>25.00%</td>
<td>2.0</td>
<td>9.00</td>
</tr>
<tr>
<td><strong>Total cost of the ration (daily consumption per animal)</strong></td>
<td></td>
<td></td>
<td>$11.80 – U$0.87</td>
</tr>
</tbody>
</table>

Traditional feeding has a cost of $27.00 (6 kg per day) and, adding cane co-products, we lower the price to $11.80, which represents savings of $15.20 per animal.

Fattening piglets (30 days)

The ingredients given to piglets to fatten them are presented in Table 9.

Table 9—Ingredients for fattening piglets.

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Content</th>
<th>kg of inputs</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheese whey</td>
<td>50%</td>
<td>1.5</td>
<td>$0.45</td>
</tr>
<tr>
<td>Cane juice</td>
<td>30%</td>
<td>0.9</td>
<td>$0.63</td>
</tr>
<tr>
<td>Concentrate</td>
<td>20%</td>
<td>0.6</td>
<td>$3.60</td>
</tr>
<tr>
<td><strong>Total Cost of the ration (daily consumption per animal)</strong></td>
<td></td>
<td></td>
<td>$4.68 – U$0.35</td>
</tr>
</tbody>
</table>

This portion is for piglets to be sold roasted Cuban style. Traditional feeding has a cost of $12.00 (2 kg daily) and, with the addition of cane co-products, we lower the cost to $4.80, which represents a saving of $7.20 per animal.

Fattening pigs

The ingredients used for fattening pigs are given in Table 10.

Table 10—Ingredients for ration for fattening pigs.

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Content</th>
<th>kg of inputs</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheese whey</td>
<td>50 %</td>
<td>3.0</td>
<td>0.90</td>
</tr>
<tr>
<td>Cane juice</td>
<td>30 %</td>
<td>1.9</td>
<td>1.33</td>
</tr>
<tr>
<td>Concentrate</td>
<td>20 %</td>
<td>1.2</td>
<td>5.40</td>
</tr>
<tr>
<td><strong>Total cost of the ration (daily consumption per animal)</strong></td>
<td></td>
<td></td>
<td>$7.63 – U$0.57</td>
</tr>
</tbody>
</table>
The traditional food ration has a cost of $31.50 (7 kg/day) and, with the addition of cane co-products, is reduced to $7.63, saving $23.87 per head.

**Sustainable agriculture**

Fruits and vegetables are fertilised with organic fertiliser bought from CM and produced by the same farm from manure (worm compost) and residuals from a biodigester for the production of methane gas. To control pests and diseases, natural traps and bio products are used.

**Growing vegetables**

**Plot preparation**

The soil is loosened with a pick and shovel to a depth of 30 cm and compost is added to give good conditions for plant development.

Lime is added.

**Buying plants**

The plants that are used have been handled and selected previously for their optimum growing and maturing properties and the size of their fruits. The plants are bought by a filial firm, VITROMOTZ.

**Sowing**

At transplanting, the roots are disinfected with a solution of ‘Bordalese broth’ and are inoculated with mycorrhizae to stimulate root development to improve the growing of the plant.

**Fertilisation**

During the first 10 days of development, foliar applications are made with liquid fertiliser, which gives nutrients and salts needed for an optimum growing and production of a good number of flowers and fruits. As a supplement, the crops are fertilised monthly.

**Biological control of pests**

To control pests, biological methods from plant extracts and infusions, such as garlic, onion, cempasuchil, basil, peppers, rue, chamomille and neem are used. Chemical insecticides are not used.

**Diseases**

When there are fungus problems such as smut, control is effected by applying a solution made of cupper sulfate and lime, called ‘Bordalese broth’. It is made with 1 kg of copper sulfate and 1 kg of hydratated lime dissolved in 100 litres of water.

**Fertigation**

Water from the fish ponds is used for irrigation so that all the nutrients and organic matter are used.

**Costs and Profits**

The costs and profits of growing vegetables are presented in Table 11.

<table>
<thead>
<tr>
<th>Vegetable</th>
<th>Production cost ($)</th>
<th>Production value ($)</th>
<th>Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tomatoes (\textit{Lycopersicum esculentum})</td>
<td>2062.00</td>
<td>3000.00</td>
<td>$938.00 – U$69.48</td>
</tr>
<tr>
<td>Cucumber (\textit{Cucumis sativus} L.)</td>
<td>946.00</td>
<td>1600.00</td>
<td>$654.00 – U$48.44</td>
</tr>
<tr>
<td>Pumpkin (\textit{Cucurbita mixta})</td>
<td>377.00</td>
<td>1,080.00</td>
<td>$703.00 – U$52.07</td>
</tr>
<tr>
<td>Radish (\textit{Raphanus sativus})</td>
<td>392.00</td>
<td>800.00</td>
<td>$408.00 – U$30.22</td>
</tr>
</tbody>
</table>

**Price**

Not having intermediaries, all products are sold at the regional market price, which makes the production more profitable.
Analysis of cost-benefit

It is important to emphasise that the biggest profit is for the environment by not using agrochemicals, insecticides, herbicides and pesticides. It favours not only the direct health of consumers, but it also protects land, streams, and aquifers. There is some reduction in yields, but this is justified because it spares the depreciation of the biological capital.

Biogas production

As part of an environmental plan for the pigs and cattle, Teresita Farm has a biodigester, Hindu type, of continuous flow, that permits the use of manure and other organic wastes. The volume of the biodigester is 3 m³ and it is fed daily with 35 kg of fresh manure, mixed with 70 litres of hot water at 45°C.

With the biodigester, methane gas is produced for use at the farm, and its residue is used as fertiliser for the vegetables and to feed the fish. A schematic diagram of the biodigester is presented in Figure 6.

Fish pond

The farm has 4 ponds with a capacity of 2000 fish each. The biofertiliser from the digester is used to initiate the production of algae and this begins a trophic chain to feed the fish.

The residual water is used to irrigate vegetables, giving very good results, due to the fact that this water has a good load of nutrients.

Economical impact

It is possible to deduce from Tables 12 and 13 that, during a crisis period in the Mexican sugar industry, both mills produced good financial results.
**Table 12**—Economical Results Central Motzorongo mill 2005–2008.

<table>
<thead>
<tr>
<th>INGENIO: CENTRAL MOTZORONGO, S.A. DE C.V.</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Results 2005 – 2008 (thousand of pesos $)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CONCEPT</strong></td>
<td>2005</td>
<td>2006</td>
<td>2007</td>
<td>2008</td>
</tr>
<tr>
<td>INCOME</td>
<td>1 141 371</td>
<td>1 171 757</td>
<td>1 110 305</td>
<td>986 569</td>
</tr>
<tr>
<td>Sales cost</td>
<td>1 030 095</td>
<td>1 008 431</td>
<td>1 038 229</td>
<td>901 930</td>
</tr>
<tr>
<td>Profit (Losses)</td>
<td>111 276</td>
<td>163 326</td>
<td>72 076</td>
<td>84 639</td>
</tr>
<tr>
<td>Operational expenses</td>
<td>47 033</td>
<td>54 952</td>
<td>58 324</td>
<td>68 544</td>
</tr>
<tr>
<td>Profit (Losses) operation</td>
<td>64 243</td>
<td>108 374</td>
<td>13 752</td>
<td>16 095</td>
</tr>
<tr>
<td><strong>PRODUCTION DATA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cane grinding tonnes</td>
<td>1 270 426</td>
<td>1 089 368</td>
<td>1 176 626</td>
<td>1 338 529</td>
</tr>
<tr>
<td>Sugar produced tonnes</td>
<td>136 753</td>
<td>123 647</td>
<td>127 574</td>
<td>150 285</td>
</tr>
<tr>
<td>Molasses tonnes</td>
<td>49 802</td>
<td>38 440</td>
<td>40 713</td>
<td>65 466</td>
</tr>
</tbody>
</table>

**Table 13**—Economical Results El Refugio mill 2005–2008.

<table>
<thead>
<tr>
<th>INGENIO EL REFUGIO, S.A. DE C.V.</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>RESULTS 2005 – 2008 (THOUSAND OF PESOS $)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CONCEPT</strong></td>
<td>2005</td>
<td>2006</td>
<td>2007</td>
<td>2008</td>
</tr>
<tr>
<td>INCOMES</td>
<td>286 641</td>
<td>268 901</td>
<td>286 828</td>
<td>270 986</td>
</tr>
<tr>
<td>Sales cost</td>
<td>249 518</td>
<td>224 964</td>
<td>265 807</td>
<td>240 238</td>
</tr>
<tr>
<td>Profit (Losses)</td>
<td>37 123</td>
<td>43 937</td>
<td>21 021</td>
<td>30 748</td>
</tr>
<tr>
<td>Operational costs</td>
<td>14 799</td>
<td>15 174</td>
<td>16 812</td>
<td>21 798</td>
</tr>
<tr>
<td>Profit (losses) operation</td>
<td>22 324</td>
<td>28 763</td>
<td>4209</td>
<td>8950</td>
</tr>
<tr>
<td><strong>PRODUCTION DATA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cane grinding tonnes</td>
<td>426 510</td>
<td>343 374</td>
<td>383 343</td>
<td>448 016</td>
</tr>
<tr>
<td>Sugar produced tonnes</td>
<td>46 143</td>
<td>39 267</td>
<td>40 786</td>
<td>49 866</td>
</tr>
<tr>
<td>Molasses tonnes</td>
<td>17 734</td>
<td>12 512</td>
<td>13 049</td>
<td>22 971</td>
</tr>
</tbody>
</table>

**Conclusions**

Co-products of the cane provide an alternative to increase the productivity of the factories, to improve the development of new areas of interest, and to promote parallel businesses and receive greater profits.
AMÉLIORATION DE PRODUCTIVITE DANS LES USINES SUCRIERES AVEC L'INTEGRATION DE L'UTILISATION DE CO-PRODUITS

Par

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MOTS-CLÉS: Productivité, Bagasse Hydrolysée, Compost; Production de Biogaz et ‘Mélasse Riche En Sucre’.

Résumé

CETTE COMMUNICATION décrit un programme incitatif pour les travailleurs par le biais d'un modèle de développement, en ayant recours principalement les co-produits de la canne à sucre; utilisés de différentes façons à 25 kilomètres de l'usine de ‘Granja Teresita’. L'usine a une unité pour l'hydrolyse de la bagasse de la canne à sucre dans deux réacteurs individuels, à l’aide d’un procédé physique (utilisant la vapeur à 1.4 MPa) et les aires de compostage de résidus (90 jours, sans procédé enzymatique). La production est vendue à la ferme. Pour les bovins et caprins, la partie supérieure de la canne est utilisée avec la mélasse, la bagasse hydrolysée, la fibre humide provenant des décanteurs et d’autres résidus agricoles de la région. Pour les porcins, la mélasse ‘B’ invertie et d’autres compléments locaux sont utilisés. Pour l'agriculture durable, les engrais organiques (compost), produits à partir des sous-produits de l’usine (boues, bagasse, cendres, etc...) et vermi compost, produit localement, sont utilisés avec du fumier d’agneau. Toutes une gamme d’espèces est cultivée comprenant le maïs et le sorgho et d’autres espèces horticoles, et il y a également une industrie aquacole.

MEJORANDO LA PRODUCTIVIDAD EN EL CENTRAL AZUCARERO MEDIANTE LA INTEGRACIÓN DE COPRODUCIOS

Por

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PALABRAS CLAVE: Productividad, Bagazo Hidrolizado, Compost, Biogás, Mielas Ricas Invertidas.

Resumen

EL ARTÍCULO muestra un ‘Programa Incentivo’ para trabajadores, a través de un modelo de desarrollo, empleando fundamentalmente coproducios de la caña de azúcar, utilizados en diferentes modos en la Granja teresita, a 25 kilómetros del Central. El Central posee una planta de hidrolizar bagazo en dos reactores batch mediante un proceso físico (con vapor a 1,4MPa) y áreas para composteado de residuales (90 días sin proceso enzimático) y vende la producción al rancho. Para vacunos y caprinos, empleamos las ‘puntas’ de caña con melazas, bagazo hidrolizado, fibra húmeda de caña ‘cush-cush’ separadas en los filtros clarificadores y otros residuales agrícolas de la región.
Para cerdos utilizamos mieles B invertidas y complementos producidos localmente. Para agricultura sostenible se aprovechan fertilizantes orgánicos (compost) fabricados a partir de productos del Central (tortas de los filtros al vacío, bagazo, cenizas, etc.) y compost de lombrices, producido localmente, junto con excretas de ovejas. Se cosechan un conjunto de cultivos incluyendo maíz, sorgo y hortalizas, también existe una industria acuícola.
EPA CHALLENGES FOR BAGASSE FIRED POWER STATIONS

By

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KEYWORDS: Cogeneration, Environmental Impact, Emissions.

Abstract

Traditionally, the sugar industry has been treated leniently with respect to emissions standards but, as it focuses more on electricity as a profitable by-product, that is changing even though bagasse is a renewable fuel. Nowhere is that more the case than at US Sugar’s Clewiston factory in Florida: even though it is not a major exporter of electricity, when it installed a new boiler, the factory was obliged to conform with stringent EPA standards. The challenges imposed by the standards are discussed together with the engineering solutions and the results obtained. The outline specification was for a 500 000 lbs/h (~226 800 kg/h) boiler delivering 600 psig, 750°F (~4137 kPa, ~399°C) steam when firing bagasse. The main challenges were seen in obtaining the 0.026 lbs/MMBTU (~24 mg/Nm³) PM10 limit and the original 0.12 lbs/MMBTU (~70 ppmvd) NOX limit without exceeding the 0.38 lbs/MMBTU (~363 ppmvd) CO limit or the 20 ppmvd ammonia slip limit. Continuous monitoring was required. Engineering was supported by fluid dynamic studies, in particular with respect to the NOX and CO profiles in the furnace: i) maximum NOX reduction was required from the urea injection system so location was critical; and ii) engineering down combustion NOX increases CO. In the event, the unit comfortably passed all tests. The variable OFA nozzles which had been installed proved particularly useful in tuning the boiler and the low uncontrolled NOX levels [meaning there will be reduced urea charges] were pleasing to see. While these stringent requirements are unlikely to be applied to other bagasse boilers in the short term, the lessons learned will make it possible to rise to those challenges when they arise.

Introduction

The cane sugar industry has developed export cogeneration gradually over several decades, during which time many of the projects have been treated, from the emissions point of view, as no different to any other sugar industry project.

That has frequently meant a very generous treatment compared to the requirements if, for instance, power utility standards had been applied.

There have been exceptions over the years of course, most notably the stations on the French islands [Bois Rouge, Le Gol and Le Moule] and the Florida Crystals station at Okeelanta in Florida.

However, perhaps as an indication of what is to come, when US Sugar needed a new boiler [Boiler #8] for its factory at Clewiston in Florida, the state authorities tried to apply environmental requirements more strict than those at Okeelanta even though the Clewiston site is only an ad hoc electrical exporter, primarily a sugar producer.

US Sugar has a strong environmental policy so readily agreed to the approach taken but the requirements did pose a challenge to the engineers tasked with the boiler design.
Clewiston Boiler #8

The USSC requirement was for a 500 000 lbs/h [~226 800 kg/h] boiler delivering 600 psig, 750ºF [~4137 kPa, ~399°C] steam when firing bagasse as primary fuel and capable of 60% MCR output when firing oil, as a start-up and supplemental fuel.

The unit was destined to become the workhorse of the site which typically has a 200 day crop period crushing at 38 000 stcd but also operates a nominal 1500 t/d RSO refinery throughout the year.

It therefore had to operate 11 months a year without difficulty, much of that with a high turn-down ratio [capacity as low as 40–50% MCR during off-crop].

A conventional single pass, bi-drum design was adopted from the beginning, but a quick glance at the general arrangement immediately shows some unusual features (Figure 1):

- a continuous ash discharge [CAD] stoker instead of steam cleaned pinhole grate;
- an exceptionally tall furnace for a bagasse fired boiler;
- two stage superheater with inter-stage attemperation;
- flue gas scrubbing and a five field electrostatic precipitator [ESP].
The superheater arrangement is a result of the need for the high turn-down ratio but the others, as discussed later, and other less obvious features are all related to the emissions standards imposed.

The other key aspect was the nature of the bagasse: Clewiston is on far sandier soil than most of the Florida industry so bagasse ash levels can be very high and during certain periods can reach 10%.

**EPA requirements**

In general, the emissions standards in the USA are expressed in terms of pounds weight of a particular emission per million BTUs [lbs/MMBTU] of gross heat input, something which makes it difficult to express them exactly in more conventional terms or to compare them with the standards in other countries which are typically based on emission concentrations per normal cubic metre of flue gas referred to some standard condition.

Another issue is the difference in conditions applied around the world, a value which is critical to normalising for comparison purposes.

The original indications from the authorities were that they would want a NOₓ limit of 0.12 lbs/MMBTU and that was the basis that engineering started with.

However, when the permit was issued some 8 months later, they had agreed that such a level was unrealistic so the permit for Clewiston’s Boiler #8 required the following (Table 1).

<table>
<thead>
<tr>
<th>Air pollutant</th>
<th>Maximum concentration</th>
<th>Units</th>
<th>Approximate alternative units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particulate matter [PM₁₀]</td>
<td>0.026</td>
<td>lbs/MMBTU</td>
<td>~24 mg/Nm³</td>
</tr>
<tr>
<td>Opacity</td>
<td>20</td>
<td>%</td>
<td>n/a</td>
</tr>
<tr>
<td>Sulfur dioxide</td>
<td>0.06</td>
<td>lbs/MMBTU</td>
<td>~32 ppmvd*</td>
</tr>
<tr>
<td>Nitrogen dioxide</td>
<td>0.14</td>
<td>lbs/MMBTU</td>
<td>~81 ppmvd*</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>0.38</td>
<td>lbs/MMBTU</td>
<td>~363 ppmvd*</td>
</tr>
<tr>
<td>Volatile organics [as C₂H₆]</td>
<td>0.05</td>
<td>lbs/MMBTU</td>
<td>~100 ppmvd*</td>
</tr>
<tr>
<td>Ammonia Slip</td>
<td>20</td>
<td>ppmvd*</td>
<td>n/a</td>
</tr>
<tr>
<td>Lead</td>
<td>3.8 x 10⁻⁵</td>
<td>lbs/MMBTU</td>
<td></td>
</tr>
<tr>
<td>Mercury</td>
<td>3.0 x 10⁻⁶</td>
<td>lbs/MMBTU</td>
<td></td>
</tr>
<tr>
<td>Metals (sum of 8)</td>
<td>1.0 x 10⁻⁴</td>
<td>lbs/MMBTU</td>
<td></td>
</tr>
<tr>
<td>Hydrogen chloride</td>
<td>0.02</td>
<td>lbs/MMBTU</td>
<td></td>
</tr>
</tbody>
</table>

* at 7% O₂

The permit enforcement for NOₓ and CO was to be with a Continuous Emissions Monitoring System [CEMS] so there was no question of being out of permit as is often the case elsewhere.

The only concessions were that the limits were on a rolling average basis. It was accepted that no chemical scrubbing would be used and, therefore, that the fuel-related pollutants [SOₓ, heavy metals and HCl] would be whatever they would be.

There was, however, still a need to be sure that the permit levels were not exceeded, so bagasse samples were analysed over an extended period in order to verify this and, coincidentally, to provide design data for the boiler.
Particulate matter limits are very typical of the environmental standards imposed around the world but the permit level at Clewiston is remarkably low (Figure 2).

\[
\text{PM}_{10}, \text{ sometimes referred to as the 'thoracic' limit, refers to particles equal to or smaller than } 10 \, \mu \text{m. The limits shown have all been normalised to } 12\% \, \text{CO}_2 \text{ by volume dry.}
\]

Similarly, the NO\textsubscript{x} limit – not a typical requirement – is remarkably low and lower even than that at Okeelanta, only a few miles south (Figure 3):

The CO limit, on the other hand, was not considered too onerous if taken on its own. The problem is, however, that trying to drive down NO\textsubscript{x} by careful furnace design tends to drive up the CO content of the flue gas.

**Engineering**

USSC wanted a boiler which was efficient [in order to maximise the bagasse available for off-crop use], easy to operate and maintain, able to operate at a high turndown ratio and, of course, be permit compliant under all operating conditions.

Experience at Okeelanta showed that any form of intermittent discharge grate would result in permit excursions during cleaning. The ash content of the bagasse indicated that this would be quite frequent at times. It was, therefore, decided from the outset that the unit would be equipped with a CAD stoker in order to avoid that problem and assist with ease of operation. That decision also gave USSC the option of burning other fibrous fuels during off-crop after the surplus bagasse supply was exhausted.

The Thermal Energy Systems stoker is engineered to minimise maintenance: it has larger diameter shafts than comparable units, very robust catenary tensioned chains and high temperature castings throughout. In order to deliver the 227 t/h of steam, it would have to be one of the largest stokers in the world.
Having established the grate concept, the focus of the engineering for Boiler #8 moved to the furnace and the need to control NO\textsubscript{x}, ammonia slip and CO. Selective Catalytic Reduction [SCR] of NO\textsubscript{x} was considered inappropriate and therefore the only practical alternative, non-catalytic reduction [SNCR], was adopted. The significance of that decision was that SNCR, which involves injecting ammonia or, more conveniently, urea into the furnace in order to reduce the NO\textsubscript{x} content to molecular nitrogen [N\textsubscript{2}], is only 50% effective at best so untreated NO\textsubscript{x} levels had to be no more than 0.28#/MMBTU, a low target.

One of the other issues with SNCR is that it is most effective within tight temperature ranges, so it was necessary to predict the temperature profiles in the furnace for the full range of possible operating conditions and to design the urea injection system to cover that range. In addition, over-treating with urea leads to ‘ammonia slip’: surplus ammonia being released to the atmosphere in one form or another. When SNCR is adopted, a limit on ammonia slip of 20 ppmvd [at 7% O\textsubscript{2}] is imposed.

SNCR is a highly specialised technology so the supplier was selected from an early stage and the furnace engineering developed in conjunction with him. It was clear that computerised fluid dynamics would be needed to determine the shape of the furnace, the optimum way to inject the secondary combustion air to approximate perfect mixing within the furnace volume and the optimum injection points for the urea injection.

For the latter two challenges, the systems had to be capable of working within the full range of possible operating conditions, whether that be steam generating capacity or fuel characteristics.

The boiler was modelled using the ‘Furnace’ computerised fluid dynamics [CFD] code developed in Australia using over ¾ million individual cells. In the end, because of the relationship between NO\textsubscript{x} and CO, it was decided to use CO concentration in addition to gas velocities and particle trajectories to analyse the mixing within the furnace.

The output from the modelling was portrayed as a series of elevation and plan sections showing predicted values for the gas velocity vectors, temperatures, particle trajectories, O\textsubscript{2} concentrations and CO concentrations. Figure 4 shows examples of two such portrayals:

![Fig. 4—Example Portrayals from CFD Analysis.](image-url)
The left hand image shows the predicted gas velocities and directions for a particular configuration. [Dark blue is up to 3 m/s and the green – the highest velocity in this instance – is 12 to 15 m/s.] The right hand image shows the predicted gas temperatures for a different configuration. [Dark blue is up to 100°C and the darkest reds are in excess of 1300°C.] Other portrayals showed the same parameters in plan sections and other parameters included particle tracks, oxygen levels and CO levels.

Once the basic model had been established it was possible to evaluate various configurations, in particular of the overfire air [OFA]: both the percentage of total air applied as OFA and the number and arrangement of OFA nozzles. The ultimate objective was to approximate a perfectly mixed furnace and hence minimum CO production with an understanding of the temperature profile and hence the locations for urea injection under various load conditions.

Part of the solution ultimately adopted was to use variable throat OFA nozzles specifically developed for the project so that the injection profile could be changed during the operation of the boiler and the urea injection optimised for different steam output conditions.

Having finalised the furnace, it was possible to proceed with the remaining thermal design and the design of the boiler ancillaries. Allowance had to be made for the additional gas burden imposed on the system by the injection of the urea solution: the resultant ammonia [and reaction products] plus the carrier water. The aspect relevant to this paper was the flue gas treatment in order to achieve the required particulates levels.

It was clear that an electrostatic precipitator [ESP] was going to be an essential part of the solution required but it would only be part of the total solution. The main issue with ESPs on fibrous fuel boilers is that the discards, containing activated carbon from semi-combusted [in this case] bagasse, are highly flammable so the ESP should be operated under positive pressure to minimise the gas oxygen content and avoid fires.

That places the ID fan before the ESP and hence exposes it to the erosive grit content of the flue gas. In addition, ESPs are not particularly good at collecting carbon particles: there is a tendency for them to break free again from the plates and pass up the stack.

USSC, as part of its ongoing environmental impact abatement policy, had recently retro-fitted one of its existing boilers with a non-saturating scrubber system, the water uptake rate being carefully controlled to avoid saturating the gas which would result in condensation and consequently corrosion within the ESP.

What was not understood at the time was that the ash content of the Clewiston fuel would essentially be calcined in the furnace and form a concrete in such scrubbers.

The system adopted for Boiler #8 was therefore a pair of non-saturating Thermal Energy Systems cyclonic scrubbers before the ID fan, followed by a five field ESP after it. The use of five fields was to ensure that permit levels would still be achieved even when rapping one of the five.

The cyclonic scrubbers use a highly turbulent venturi inlet section where the gas is sprayed, followed by a high-g cyclonic section to separate the water again, together with the scrubbed solids.

**Results**

The engineering of this complex boiler started in March 2003 and commissioning started in late January 2005 when the first oil was fired to warm up and dry out the unit. The formal testing of the unit took place just before Easter in that year, very much towards the end of crop and not long after first firing bagasse.

The environmental tests were conducted by specialist consultants on behalf of Florida State using their own portable instruments which were also used to calibrate the CEMS. The first values, compared to the permit values, are presented in Table 2.
### Table 2—Measured values of pollutants in the Clewiston boiler flue gas.

<table>
<thead>
<tr>
<th>Air pollutant</th>
<th>Maximum permitted</th>
<th>Measured value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particulate matter [PM$_{10}$]</td>
<td>0.026</td>
<td>0.0039</td>
<td>lbs/MMBTU</td>
</tr>
<tr>
<td>Opacity</td>
<td>20</td>
<td>n/a</td>
<td>%</td>
</tr>
<tr>
<td>Nitrogen dioxide</td>
<td>0.14</td>
<td>0.131</td>
<td>lbs/MMBTU</td>
</tr>
<tr>
<td>Ammonia Slip</td>
<td>20</td>
<td>26.2</td>
<td>ppmvd</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>0.38</td>
<td>0.354</td>
<td>lbs/MMBTU</td>
</tr>
<tr>
<td>Volatile organics</td>
<td>0.06</td>
<td>0.012</td>
<td>lbs/MMBTU</td>
</tr>
</tbody>
</table>

The measured values were each the average of three runs and the boiler was generating an average of 500 853 lbs/h of steam at the specified conditions. Opacity, an alternative measurement to the PM$_{10}$ was not measured because PM$_{10}$ was. It can be seen that, even at this early stage, the boiler was running well: only the ammonia slip was outside of permit value, something which was put down to incomplete commissioning of the SNCR system. It was soon brought under control and within permit once the SNCR system had been fully commissioned and tuned.

The variable OFA nozzles which had been installed proved particularly useful in tuning the boiler and the low uncontrolled NO$_x$ levels [meaning there will be reduced urea charges] were pleasing to see.

The issue of the formation of a sort of concrete in the scrubbers, as referred to early, was unexpected and caused blockages in the scrubbers’ outlets from time to time. In the end, the factory engineers came up with an ingenious solution by designing and installing macerators in the bases of the scrubbers. These are operated typically once a shift to break up any lumps of this concrete which might have broken lose from the walls so that they are flushed away by the scrubber water.

**Conclusions**

It is accepted that the stringent requirements of the Florida DEP and Federal EPA are unlikely to be applied to other sugar industry boilers in the short term – not even in other states of the USA – but the important point is that, with the lessons learned at Clewiston, it will be possible to rise to those challenges when they arise.
DÉFIS APE POUR LES CENTRALES THERMIQUES UTILISANT LA BAGASSE

Par

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MOTS-CLÉS: Cogénération, l'Impact Environnemental, Émissions.

Résumé

TRADITIONNELLEMENT, l'industrie sucrière a été traitée avec indulgence quant aux normes d'émissions, mais comme elle met l'emphasis de plus en plus sur la production de l'électricité comme sous-produit rentable, cette façon de voir est en train de changer, même si la bagasse est une source renouvelable d'énergie. Cela est le cas de l'usine de « US Sugar’s Clewiston » en Floride: même si elle n'est pas une importante exportatrice de l'électricité, lorsqu'elle avait installé une nouvelle chaudière, l'usine a été contrainte de se conformer aux normes strictes de l’APE. Les défis imposés par les normes sont traités avec les solutions d'ingénierie apportées et les résultats obtenus.

La spécification sommaire a été pour une chaudière de 500 000 lbs/h (~ 226 800 kg/h) produisant de la vapeur à une pression de 600 lbs/psig, 750°F (~ 4137 kPa, ~ 399 °C) quand la bagasse est utilisée comme combustible. Les principaux défis étaient d'obtenir la limite de 0.026 lbs/MMBTU (~ 24 mg/Nm³) limite PM10 et l'initial de 0,12 lbs/MMBTU [ppmvd ~ 70] NOX sans dépasser la limite de CO de 0.38 lbs/MMBTU [ppmvd ~ 363] où la limite d'ammoniac de 20 ppmvd. Il était nécessaire d’avoir une surveillance continue. L’ingénierie avait l’apport des études dynamiques des fluides en particulier par rapport aux profiles de NOx et CO dans les chaudières : i) une réduction maximale de NOx était requise du système d'injection de l'urée, donc son emplacement était critique ; et ii) en manœuvrant afin de réduire le NOx de combustion, le CO augmente. Dans ce cas, l'unité a satisfait avec une marge confortable tous les tests. Les buses OFA variables qui avaient été installées se sont avérées particulièrement utiles dans le réglage de la chaudière et il était agréable d’observer les faibles niveaux de NOx incontrôlées [indiquant qu’il y aurait une charge réduite d’urée]. Alors qu’il est peu probable que les exigences strictes seraient appliquées aux autres chaudières à bagasse à court terme, les leçons apprises permettront de relever ces défis lorsqu'ils surviennent.

LOSS RETOS DE LA ADMINISTRACIÓN DE PROTECCIÓN AMBIENTAL (EPA) PARA LAS ESTACIONES DE FUERZA ALIMENTADAS CON BAGAZO

Por

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PALABRAS CLAVE: Cogeneración, Impacto Ambiental, Emisiones.

Resumen

TRADICIONALMENTE la industria azucarera ha sido tratada benignamente con respecto a los estándares de emisiones, pero en cuanto esta se enfoca, cada vez más, hacia la generación de electricidad como un subproducto rentable, esto va cambiando, aunque el bagazo es un combustible renovable. Ningún caso mejor que el acontecido con la fábrica de azúcar estadounidense en Clewiston, Florida, que a pesar de no ser una importante “exportadora” de electricidad, cuando instaló una caldera, la fábrica fue obligada a ajustarse a los estrictos estándares de la EPA. Se discuten los retos impuestos por los estándares, junto con las soluciones ingenieriles y los resultados obtenidos.. Las especificaciones fueron una caldera de una capacidad de 500 000 lbs/h (= 226 800 kg/h), generando vapor a 600 psig, 750° F (=4137 kPa a 399° C) cuando quemaba bagazo.

8
El principal reto lo constituyó el obtener el límite de 0,026 lbs/MMBTU (224 mg/Nm³) PM y el límite original de 0,12 lbs/MMBTU (= 70 ppmvd) NOx, sin exceder el límite de 0,38 lbs/MMBTU (= 363ppmvd) CO ó el límite de los 20 ppmvd de desprendimiento de amonía. Se requiere un monitoreo continuo. La ingenierización se apoyó en estudios de dinámica de fluidos, en particular con respecto a los perfiles de NOx y CO en hornos; I) se requería una reducción máxima de NOx del área del sistema de inyección de urea, de aquí que la ubicación fuera crítica, y II) ingeniarizar la caída de NOx de la combustión que aumenta el CO. Afortunadamente, la unidad pasó todas las pruebas cómodamente. La variable de las toberas OFA que fueron instaladas probó ser especialmente útil para ajustar la caldera y los incontrolables bajos niveles de NOx (significando que habrá reducidas cargas de urea), algo muy agradable de apreciar. No obstante el hecho de que estos exigentes requerimientos son poco probables de ser aplicados a otras calderas de bagazo, la lección aprendida hará posible erguirse ante estos retos cuando aparezcan.
BUTANOL PRODUCTION FROM SUGARCANE JUICES

By

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KEYWORDS: Butanol, Fermentation, Sugar Juices, Biomass.

Abstract

BUTANOL is an aliphatic saturated alcohol with the molecular formula of C₅H₁₀OH, which can be used as a transportation fuel, an intermediate and a solvent for a wide variety of chemical applications. The acetone-butanol fermentation was the standard for industrial production of solvents until the 1950s. Modern microbiological techniques have improved the original organism such that it produces high levels of butanol rather than mixed solvents. Butanol has many advantages as an alternative fuel source; 1) a higher energy content, 2) usable in existing pipelines, 3) easy to blend with gasoline. Butanol can be produced from sugarcane juice, molasses or sugars from bagasse hydrolysates using a strain of Clostridium beijerinckii. Sugarcane juice and molasses ferment directly to butanol. The yield of butanol was 0.30 g/g sugar from molasses and 0.34 g/g sugar from juice whereas equivalent sucrose concentrations produced 0.27 g butanol per g sugar. Details of the economics for a viable production of butanol from sugarcane products are presented.

Introduction

The acetone butanol ethanol (ABE) fermentation by Clostridium acetobutylicum is one of the oldest known industrial fermentations. It was ranked second only to ethanol fermentation by yeast in its scale of production, and is one of the largest biotechnological processes ever known. Prior to the 1950s, the industrial solvents acetone, n-butanol and isopropanol (generically referred to as butanol and propanol in this discussion) were produced by fermentation (Figure 1).

Fig. 1—Acetone-butanol plant, pre 1950, 600 000 gallon fermentation capacity, Terre Haute, Ind.
Historically, two clostridial species, *Clostridium acetobutylicum* or *Clostridium butylicum* were the fermentation organisms of choice. In a typical ABE fermentation by *C. acetobutylicum*, butyric, propionic, lactic and acetic acids are produced first, the culture pH drops, and the culture undergoes a metabolic ‘butterfly’ shift, then butanol, acetone, isopropanol and ethanol are formed (Zheng et al., 2009).

The butanol yield from glucose is low, typically around 15 percent and rarely exceeds 25%. The production of butanol is limited by severe product inhibition. Butanol at a concentration of 1 percent inhibits cell growth and fermentation by 20% while 1.6% inhibits growth 100%. The butanol concentration in the broth in conventional ABE fermentations is usually less than 1.3 percent (Jones and Woods, 1986).

The push for renewable fuels has re-ignited the interest in butanol production by fermentation. Butanol is both an important industrial solvent and potentially a better fuel than ethanol (Table 1).

| Table 1—Properties of Alternative Fuels (Ramey, 2007). |
|-----------------|---------------------------------------------------|-----------------|
|                 | Ethanol              | Butanol     | Gasoline     |
| BTU/ gal(gross caloric value) | 84k                    | 110k        | 115k          |
| Octane(RON)     | 92                    | 94          | 96            |
| Air fuel ratio(mass of air to mass of fuel) | 9                      | 11–12       | 12–15         |
| Vapour pressure psi@100F  | 2                      | 0.33        | 4.5           |

BTU=1.05 x10³ J; psi= 6.9 x 10³ Pa

Butanol has many advantages as an alternative fuel source; 1) a higher energy content, 2) usable in existing pipelines, 3) easy to blend with gasoline. Because of its low solubility, butanol is less likely to separate from a fuel blend in the presence of water than is ethanol.

The production of butanol from sugars goes by the biochemical route where acetoacetyl-CoA is produced from glucose and then simultaneously split to acetone and butyrate followed by the conversion of butyrate to butanol and, depending on the organism strain, the conversion of the acetone to propanol. There have been numerous attempts to manipulate the genetics of these organisms to separate acetone production from butanol production. This has not been completely successful as both acetone and butanol share a common intermediate (Figure 2). Attempts to block acetone production to favour butanol production usually result in a loss of butanol yield.

![Biochemical pathway leading to butanol and acetone](image)
In the past twenty or so years, there have been numerous engineering attempts to improve butanol production in the ABE fermentation, including cell recycling and cell immobilisation to increase cell density and reactor productivity, and use of extractive fermentation to minimise product inhibition. The yields for ABE fermentations are still less than 2 percent in butanol concentration, 4.46 g/L/h productivity, and a yield of around 25 percent from glucose (Ezeji et al., 2007).

Optimisation of the ABE fermentation process has long been a goal of industry. As with any biofuel, the viability of the ABE fermentation will depend on feedstock cost and microbial productivity. The market demand for butanol is expected to increase dramatically if green butanol can be produced economically from low cost sugars (i.e. biomass derived). Recent research has focused on utilisation of sugars from lignocellulose conversion, with butanol being an alternative to ethanol production (Qureshi et al., 2007).

There is little published information on the conversion of ‘traditional’ feedstocks available from the cane sugar industry to butanol. This study was conducted due to our interest in bringing biofuel production to the Louisiana sugar industry.

**Materials and methods**

**Microorganism and inoculum preparation**

A strain of *Clostridium beijerinckii* (obtained from the Centraalbureaus voor Scimmelecultures in the Netherlands) was used in this research. Bacterial spores (200 μL) were heat shocked for 10 min at 80°C followed by cooling in ice, then inoculated into 27 mL tryptone-glucose-yeast extract (TGY) medium in 30 mL screw capped Pyrex tubes and incubated anaerobically for 12–16 h at 34°C (Qureshi et al., 2008).

**Carbon source**

Different carbon sources were used: sucrose (laboratory grade sucrose, Sigma Chemical co., St. Louis Mo.), blackstrap molasses (containing of 33.4% sucrose, 5.4% glucose, 7.3% fructose, 16.5% ash [conductivity ash] as % total solids 41.9% true purity), raw juice (12.35% sucrose, 0.38% glucose, 0.74% fructose, ash content not determined, values on juice volume), and glucose derived from corn starch for comparison. Glucose was prepared by hydrolysis of corn starch derived malto-oligosaccharide syrups using amyloglucosidase. Enzymatic conversion was allowed to proceed until in excess of 95% of the starch was glucose.

**Batch fermentations**

Fermentation studies were conducted initially in 125 mL screw capped bottles containing 120 mL of medium, at 34°C without agitation, gas flow, or pH control. The medium contained either sucrose (5.0% in a total medium), molasses (5.9% sugars), juice (4.9% sugars), or 5% glucose for carbon source, supplemented with 1 g/L yeast extract. After sterilisation, filter-sterilised stock solutions containing (buffer: KH₂PO₄, 50 g/L; K₂HPO₄, 50 g/L; ammonium acetate, 220 g/L), (vitamins: para-amino-benzoic acid, 0.1g/L; thiamin, 0.1 g/L; biotin, 0.001 g/L), and (minerals: MgSO₄·7H₂O, 20 g/L; MnSO₄·H₂O, 1 g/L; FeSO₄·7H₂O, 1 g/L; NaCl, 1 g/L)] (Qureshi and Blaschek, 1999) were added (1 mL each). The media was then inoculated with highly motile cells of *C. beijerinckii* (6 mL cell suspension in 114 mL medium). During the course of fermentations, 4 mL samples were collected at intervals for absorbance, pH, solvents, organic acid, and sugar analysis.

**Analytical procedures**

Cell concentration was estimated from the absorbance at 600 nm. The solvents, butanol, acetone, ethanol were measured using gas chromatography on a wax column (Phenomenex ZP Wax plus). Organic acids, acetic and butyric were determined by high performance liquid chromatography (HPLC) using an anion exchange column (Dionex Ionpac AS-11). Sugars were analysed by HPLC using a K column (Biorad HPS87K).
Results and discussion

The growth curves for *C. beijerinckii* were similar for all carbon sources, achieving late exponential phase of growth around 30 h and maximum growth after 49.5 h (data not shown). The media pH in either sucrose or glucose media decreased until late exponential phase, and then rebounded (data not shown). This is a typical growth pattern for *C. beijerinckii* (Parekh *et al*., 1998; Jones and Woods, 1986) and reflects the production and then utilisation of organic acids. In most ABE fermentations, butanol production starts after the stationary phase begins. Throughout our fermentations, low levels of acetone and ethanol were continuously present and, except for the molasses fermentations, butanol concentrations increased throughout the growth phase. This pattern is indicative of continuous, efficient butanol production by *C. beijerinckii* (Jones and Woods, 1986) (Figure 3). Cultures containing molasses were acidogenic because molasses feed has high levels of acetic acid (0.65% on Brix), which slowed the start of butanol production compared to the other carbon sources. Butanol production increased rapidly after the stationary phase was achieved. Sugar juices showed rapid increases in butanol production between 12 and 49.5 h of fermentation.

![Production of acetone-butanol from individual carbon substrates by C. beijerinckii. Propanol is indicated by the ( ) symbol, butanol by ( ) symbol and total solvent by the ( ) symbol. The glucose was that obtained from corn starch hydrolysis.](image)

Juice (containing 4.9% sugars) and molasses (5.9% sugars) were the preferred substrates for butanol production by this strain (Figure 4). Higher concentrations of molasses repressed growth, probably due to osmotic effects (data not shown). In all cases 2-propanol was the largest secondary product. This product pattern is very similar to that produced by *C. butylicum*. Small amounts of ethanol were found in all samples. No differences were observed between glucose and sucrose fed
cultures in the production of butanol. These fermentations were not optimised for carbon utilisation. In all cases, residual sugars remained at the conclusion of the fermentations.

The productivity of this culture was higher on juice and molasses than on sucrose or glucose. In these, non-optimised, fermentations there were 1.6 to 1.7 times more solvent in the fermentation broth with molasses or juice as feedstock than with sugars.

On a carbon source utilised, yield to product produced (Table 2), there was about 1.3 times more solvent produced using sugarcane feedstocks than with either pure sugar or corn hydrolysate.

Table 2—Solvent* Production by carbon source.

<table>
<thead>
<tr>
<th>Carbon source</th>
<th>Solvent yield (g/g sugar utilised)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sucrose or glucose</td>
<td>0.32</td>
</tr>
<tr>
<td>Juice</td>
<td>0.42</td>
</tr>
<tr>
<td>Molasses</td>
<td>0.36</td>
</tr>
</tbody>
</table>

*n-butanol and isopropanol.
The glucose was obtained from corn starch.

The solvent produced in all cases was primarily butanol with a significant portion of isopropanol. Acetone and ethanol were either absent or present as trace components (Table 3).

Table 3—Solvent yield %* by carbon source.

<table>
<thead>
<tr>
<th>Carbon source</th>
<th>n-butanol</th>
<th>Isopropanol</th>
<th>Total solvent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sucrose or glucose</td>
<td>25</td>
<td>5</td>
<td>32</td>
</tr>
<tr>
<td>Juice</td>
<td>32</td>
<td>9</td>
<td>42</td>
</tr>
<tr>
<td>Molasses</td>
<td>27</td>
<td>7</td>
<td>36</td>
</tr>
</tbody>
</table>

*weight % of product on carbon source utilised
The differences in solvent yields, as a function of feedstock, is significant. In comparing butanol production with the alternative (ethanol), it should be kept in mind that ethanolic (yeast) fermentations have a theoretical maximum yield of 51% and take 1.65 kg of sugar to produce a litre of ethanol. The amount of sugar used and relative feedstock costs (in the US) to produce butanol are given in Table 4.

Table 4—Estimated feedstock cost to produce butanol.

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>Kg sugars/litre solvent</th>
<th>Feedstock price* (estimated)/kg ($)</th>
<th>Feedstock cost/litre product ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure sugar</td>
<td>3.90</td>
<td>0.44</td>
<td>1.72</td>
</tr>
<tr>
<td>Cane juice</td>
<td>2.97</td>
<td>0.44</td>
<td>1.31</td>
</tr>
<tr>
<td>Molasses**</td>
<td>3.47</td>
<td>0.071</td>
<td>0.25</td>
</tr>
<tr>
<td>Corn (at $4.80/bu)</td>
<td>3.90</td>
<td>0.335</td>
<td>1.31</td>
</tr>
</tbody>
</table>

*Price in US dollars for American market
** Molasses estimated at 49% fermentable sugars, $70.00/tonne.

Even though the conversion of sugar(s) to butanol/propanol is lower than conversion to ethanol, the higher BTU values for butanol and reduced fuel transport handling problems make this fermentation worth considering for fuel production. (Qureshi and Blaschek, 2000). Butanol fuel made directly from sugar juice is probably competitive with corn ethanol and that from molasses is cheaper. Improvements in yields can be expected as further efforts are made in strain improvement and as the technology matures to the equivalent of fuel ethanol production technology.

REFERENCES


PRODUCTION DE BUTANOL À PARTIR
DE JUS DE CANNE À SUCRE

Par

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MOTS-CLÉS: Butanol, Fermentation, Jus de Sucre, Biomasse.

Résumé

Le butanol est un alcool aliphatique saturé avec la formule moléculaire de C₄H₉OH, qui peut être utilisé comme un combustible de transport, un intermédiaire et un solvant pour une grande variété d'applications chimiques. La fermentation acétone-butanol était la norme pour la production industrielle de solvants jusqu'aux années 1950. Les techniques microbiologiques modernes ont amélioré le micro-organisme d'origine pour qu’il produce des niveaux élevés de butanol plutôt que de solvants mixtes. Le butanol présente de nombreux avantages comme une source de carburant de remplacement. 1) Un contenu énergétique plus élevé; 2) Une utilisation dans les pipelines existants; 3) Un mélange plus évident avec l'essence. Le butanol peut être produit à partir de jus de canne à sucre, de mélasse ou des sucres issus des hydrolysats bagasse à l'aide d'une souche de Clostridium beijerinckii. Le jus de canne et la mélasse fermentent directement en butanol. Le rendement de butanol était 0.30 g/g sucre à partir de mélasse et de 0.34 g/g à partir de jus que canne alors qu’une concentration équivalent en saccharose produit 0.27 g butanol par g de sucre. Les détails d’ordre économique pour une production viable de butanol à partir de produits émanant de la canne à sucre sont présentés.

PRODUCCIÓN DE BUTANOL DE JUGOS
DE CANA DE AZÚCAR

Por

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PALABRAS CLAVE: Butanol, Fermentación, Jugos Azucarados, Biomasa.

Resumen

El butanol es un alcohol alifático saturado con la fórmula molecular de C₄H₂OH, que puede ser usado como combustible de transporte, como intermediario y como solvente para una amplia variedad de aplicaciones químicas. La fermentación acetona-butanol fue el estándar para la producción industrial de solventes hasta los años 1950. Modernas técnicas microbiológicas han mejorado el microorganismo original en un modo tal que produce elevadas cantidades de butanol en lugar de la mezcla de solventes. El butanol tiene ventajas como fuente alternativa de combustible: 1) mayor contenido energético, 2) posible de emplear en instalaciones actuales, 3) fácil de mezclar con gasolina. El butanol puede producirse del jugo de caña de azúcar, de melazas ó de azúcares de los hidrolizados de bagazo, empleando una cepa de Clostridium beijerinckii. Los jugos de caña y las melazas se fermentan directamente a butanol. El rendimiento de butanol fue de 0.30 g/g de azúcar de melazas y 0.34 g/g de azúcares de jugos, mientras concentraciones equivalentes de sacarosa produjeron 0.27 g de butanol por gramo de azúcar. Se presentan detalles acerca de la economía para una producción viable de butanol.
SUSTAINABLE ENERGY FOR ETHANOL DISTILLERIES

By

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KEYWORDS: Vinasse Treatment, Biogas Production, Biogas from Vinasse.

Abstract
The production of ethanol from the sugar containing feedstock generates waste waters coming from the bottom of distillation towers, well-known as vinasse. These constitute the biggest load pollutant. Using a group of parameters found in a wide list of international references, the present paper shows energy balances (of steam and electricity) using Excel, to demonstrate that biogas produced from the anaerobic digestion of this polluting load, besides degrading the vinasse, can contribute to the supply of energy demand to an ethanol distillery. The results are presented for medium, low and high values of pollutant concentration. It is intended also to use this energy to feed gas burners at conventional steam generators, removing the H₂S that contains the biogas in a process called desulfurisation. At the end, the main methods for desulfurisation for this combustible gas are recommended.

Introduction
The production of ethanol from the sugar industry generates waste waters coming from the bottom of distillation towers, well-known as vinasse. These constitute the biggest load pollutant. The biogas production is one of several alternatives frequently used internationally for degradation of this polluting load.

There are reliable references about significant energy advantages that this alternative offers such as in Godbole (2002).

The target of the present paper is to show that biogas which can be generated from anaerobic digestion of vinasse in an ethanol distillery, besides degrading the vinasse, can contribute to a high percent of its energy demand.

Pollutant loads
Vinasse is defined as a solution of substances and mineral and organic salts with relative value and with potential for diverse uses. COD (Chemical Oxygen Demand) measures the value of the contamination present in vinasse.

Factor selected for this calculation
The values of load pollutant selected for this work will be those proposed by Estévez (2007a) that are shown in the Table 1.

Table 1—COD characterisation of vinasse from the cane sugar industry (Estévez, 2007a)

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Non-harvest season</th>
<th>Harvest season</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD (kg/m³)</td>
<td>60–80</td>
<td>30–40</td>
</tr>
</tbody>
</table>
As may be observed in Table 1, there are differences in COD vinasse composition generated in the harvest season period compared to those generated in the non-harvest season. This is due to a fundamental difference in the preparation of the substrate.

**Harvest season period**

To prepare the substrate, filter juices previously subjected to a purification process in the sugar factory are used. These juices can be blended with molasses B or may be added directly to reactors, as required.

**Non-harvest season: Molasses ‘B’ or second crystallisation is used.**

As the critical period for the energy demand of a distillery is the non-harvest period, because the energy from bagasse is not available, this paper will use the values of the range of the COD presented in Table 1 for this scenario. The volume of vinasse of 17.4 L vinasse/L ethanol is the value considered by this paper such as in Estévez (2007a).

**Removing polluting load and conversion to fuel (methanisation)**

Not all the COD becomes biogas. Five references are presented in Table 2 related to removal percent.

### Table 2—COD removed by anaerobic digestion.

<table>
<thead>
<tr>
<th>References</th>
<th>% of COD removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valdés (2007)</td>
<td>70.0</td>
</tr>
<tr>
<td>Estévez et al. (1975)</td>
<td>79.0</td>
</tr>
<tr>
<td>Moletta (2005)</td>
<td>80.0–95.0</td>
</tr>
<tr>
<td>Aroca et al. (2006)</td>
<td>93.0</td>
</tr>
</tbody>
</table>

**Biogas produced from removed COD**

In Table 3, three references related to removal rate are presented. It can be seen that practically they are similar.

### Table 3—Rate of removal from COD to biogas.

<table>
<thead>
<tr>
<th>References</th>
<th>Biogas production (Nm³/kg COD removed)</th>
</tr>
</thead>
<tbody>
<tr>
<td><a href="http://www.monografias.com/trabajos15/tratamiento-destileria/tratamiento-destileria.shtml">www.monografias.com/trabajos15/tratamiento-destileria/tratamiento-destileria.shtml</a> (2008)</td>
<td>0.45</td>
</tr>
<tr>
<td>Moletta (2005)</td>
<td>0.4–0.6</td>
</tr>
<tr>
<td>Aroca et al. (2006)</td>
<td>0.49</td>
</tr>
</tbody>
</table>

**Efficiency of methanisation**

The previously described process produces a methane porter gas. Its composition is presented in Table 4 from Domenech (2008a). In Aroca et al. (2006) and Molletta (2005), similar figures for methane content are given.

### Table 4—Biogas composition.

<table>
<thead>
<tr>
<th>Gas</th>
<th>Symbol</th>
<th>Vol %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>CH₄</td>
<td>55–70</td>
</tr>
<tr>
<td>Carbon dioxide carbono</td>
<td>CO₂</td>
<td>30–45</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>H₂</td>
<td>1–3</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>N₂</td>
<td>0.5–3</td>
</tr>
<tr>
<td>Hydrogen Sulfide</td>
<td>H₂S</td>
<td>1.8–3</td>
</tr>
</tbody>
</table>
The biogas is a mixture of fuels, and methane is the one that gives the energy qualities. 

**Steam and electricity balances for a typical ethanol distillery of 50 000 L/day**

Table 5 shows results of energy calculations, made by a calculation table using Excel from Microsoft Office, where the indicators and parameters discussed in Tables 1, 2, 3, and 4 are used. The steam and electricity balances for the distillery example of 50 000 L/day are shown.

The values of load pollutant are those that were presented in Table 1 and the rest of the calculations will be carried out in a range with a medium value and their two extreme values (low and high), using the previously analysed data.

**Table 5—Biogas energy available for a distillery example.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Low value</th>
<th>Medium value</th>
<th>High value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Ethanol production</td>
<td>50 000</td>
<td>50 000</td>
<td>50 000</td>
<td>L ethanol/day</td>
</tr>
<tr>
<td>3 Vinasse content</td>
<td>17.4</td>
<td>17.4</td>
<td>17.4</td>
<td>L vinasse/L ethanol</td>
</tr>
<tr>
<td>4 Ratio of COD produced</td>
<td>0.06</td>
<td>0.07</td>
<td>0.08</td>
<td>kg COD/L vinasse</td>
</tr>
<tr>
<td>5 COD removed</td>
<td>70.0</td>
<td>80.0</td>
<td>90.0</td>
<td>%</td>
</tr>
<tr>
<td>6 Ratio of biogas production</td>
<td>0.4</td>
<td>0.5</td>
<td>0.6</td>
<td>Nm³ bio/kgCOD rem</td>
</tr>
<tr>
<td>7 Biogas produced</td>
<td>14 616.0</td>
<td>24 360.0</td>
<td>37 584.0</td>
<td>Nm³ biogas/day</td>
</tr>
<tr>
<td>8 Methane in biogas</td>
<td>55.0</td>
<td>62.5</td>
<td>70.0</td>
<td>%</td>
</tr>
<tr>
<td>9 Methane produced</td>
<td>8038.8</td>
<td>15 225.0</td>
<td>26 308.8</td>
<td>Nm³ methane/day</td>
</tr>
<tr>
<td>10 Fuel oil equivalent</td>
<td>6.88</td>
<td>13.02</td>
<td>22.50</td>
<td>t fuel oil/day</td>
</tr>
</tbody>
</table>

Table 5 shows figures of equivalent fuel oil obtained by biogas production. Further on will be determined what this biogas represents in energy availability with regard to steam and electricity demands for a distillery example.

The steam and electricity generation have a first and fundamental dependence on steam parameters. For this calculation, two levels will be considered: saturated steam at 11.35 bar abs and superheated steam at 18.25 bar abs and 330ºC.

A boiler efficiency of 88% with regard to the low heating value of the fuel is assumed.

A value of 100ºC water temperature for feeding the boiler is also assumed. Such water temperature value can be assumed when the vinasse is cooled using this water, a practice used in several factories of Torula yeast in Cuba according to Doménech (2008b).

**Steam balance with saturated steam at 11.35 bar abs**

In Table 6A, the steam balance carried out for the selected distillery is presented.

**Table 6A—Steam balance with saturated steam at 11.35 bar abs.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Low value</th>
<th>Medium value</th>
<th>High value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Steam pressure</td>
<td>11.35</td>
<td>11.35</td>
<td>11.35</td>
<td>bar abs</td>
</tr>
<tr>
<td>2 Temp. steam superheated</td>
<td>185.48</td>
<td>185.48</td>
<td>185.48</td>
<td>ºC</td>
</tr>
<tr>
<td>3 Boiler Efficiency</td>
<td>88.00</td>
<td>88.00</td>
<td>88.00</td>
<td>%</td>
</tr>
<tr>
<td>4 Steam Enthalpy at boiler outlet</td>
<td>2779.95</td>
<td>2779.95</td>
<td>2779.95</td>
<td>kJ/kg</td>
</tr>
<tr>
<td>5 Feedwater Enthalpy</td>
<td>418.93</td>
<td>418.93</td>
<td>418.93</td>
<td>kJ/kg</td>
</tr>
<tr>
<td>6 Steam demand as Estévez (2007a)</td>
<td>0.294</td>
<td>0.294</td>
<td>0.294</td>
<td>t steam/hL</td>
</tr>
<tr>
<td>7 Available steam from biogas</td>
<td>4.25</td>
<td>8.04</td>
<td>13.90</td>
<td>t steam/h</td>
</tr>
<tr>
<td>8 Steam demand by Distillery</td>
<td>6.13</td>
<td>6.13</td>
<td>6.13</td>
<td>t/h</td>
</tr>
<tr>
<td>9 Steam generation by biogas</td>
<td>69.34</td>
<td>131.33</td>
<td>226.94</td>
<td>%</td>
</tr>
</tbody>
</table>
Table 6A shows results of steam generation by biogas in this steam variant. They are significant, even in the low extreme value (69.34%) with regard to steam demanded by the distillery. This confirms the benefit of using biogas. For the medium value analysed (131.33 %), the steam demand for the distillery is totally covered, which eliminates the necessity to use other fuels in the non-harvest season period.

### Table 7A—Electricity balance with saturated steam at 11.35 bar abs.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Low value</th>
<th>Medium value</th>
<th>High value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Steam pressure at turbo inlet</td>
<td>10.70</td>
<td>10.70</td>
<td>10.70</td>
<td>bar abs</td>
</tr>
<tr>
<td>2 Exhaust pressure at turbo outlet</td>
<td>2.05</td>
<td>2.05</td>
<td>2.05</td>
<td>bar abs</td>
</tr>
<tr>
<td>3 Steam temp. at turbo inlet</td>
<td>182.70</td>
<td>182.70</td>
<td>182.70</td>
<td>ºC</td>
</tr>
<tr>
<td>5 Steam Rate of Turbo generator</td>
<td>21.00</td>
<td>21.00</td>
<td>21.00</td>
<td>kg/kW-h</td>
</tr>
<tr>
<td>6 Electrical demand standard as in Estévez (2007b)</td>
<td>17.33</td>
<td>17.33</td>
<td>17.33</td>
<td>kW-h/hL</td>
</tr>
<tr>
<td>7 Available electricity from biogas</td>
<td>202.25</td>
<td>383.05</td>
<td>661.92</td>
<td>kW</td>
</tr>
<tr>
<td>8 Electricity demanded by distillery</td>
<td>361.01</td>
<td>361.01</td>
<td>361.01</td>
<td>kW</td>
</tr>
<tr>
<td>9 Electricity generation by biogas</td>
<td>56.02</td>
<td>106.11</td>
<td>183.35</td>
<td>%</td>
</tr>
</tbody>
</table>

Electricity balance with saturated steam at 11.35 bar abs

Table 7A shows the results of the electricity generation by biogas in a turbo-generator which uses direct steam from a boiler considering some data presented in Table 6A. In the worst variant from the low value using biogas, more than half of the electricity (56.02%) is produced with regard to electricity demanded by the distillery.

In this case, for the medium value of electricity produced by biogas (106.11%), there is enough to cover the electricity demand by the distillery.

### Steam balance with superheated steam at 18.25 bar abs and 330ºC

For this steam parameters level, more fuel by unit of mass will be necessary for generating the available steam from biogas. Table 6B shows that less quantity of steam will be available in this variant than in the previous one analysed.

Nevertheless, a significant 61.16% steam generation by biogas with regard to steam demand of the distillery is provided with the low value, and a large surplus in the medium (116.84%) and high values (200.16%) is achieved.

### Table 6B—Steam balance with superheated steam at 18.25 bar abs and 330ºC.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Low value</th>
<th>Medium value</th>
<th>High value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Steam pressure</td>
<td>18.25</td>
<td>18.25</td>
<td>18.25</td>
<td>bar abs</td>
</tr>
<tr>
<td>2 Temp. steam superheated</td>
<td>330.00</td>
<td>330.00</td>
<td>330.00</td>
<td>ºC</td>
</tr>
<tr>
<td>3 Boiler efficiency</td>
<td>88.00</td>
<td>88.00</td>
<td>88.00</td>
<td>%</td>
</tr>
<tr>
<td>4 Steam enthalpy at boiler outlet</td>
<td>3095.80</td>
<td>3095.80</td>
<td>3095.80</td>
<td>kJ/kg</td>
</tr>
<tr>
<td>5 Feeding water enthalpy</td>
<td>418.93</td>
<td>418.93</td>
<td>418.93</td>
<td>kJ/kg</td>
</tr>
<tr>
<td>6 Steam demand as Estévez (2007a)</td>
<td>0.294</td>
<td>0.294</td>
<td>0.294</td>
<td>t steam/hL</td>
</tr>
<tr>
<td>7 Available steam from biogas</td>
<td>3.75</td>
<td>7.09</td>
<td>12.26</td>
<td>t/h</td>
</tr>
<tr>
<td>8 Steam demand by distillery</td>
<td>6.13</td>
<td>6.13</td>
<td>6.13</td>
<td>t/h</td>
</tr>
<tr>
<td>9 Steam generation by biogas</td>
<td>61.16</td>
<td>115.84</td>
<td>200.16</td>
<td>%</td>
</tr>
</tbody>
</table>
Electricity balance with superheated steam at 18.25 bar abs and 330°C

Table 7B shows that the steam rate of the Turbo-Generator can diminish significantly with regard to Table 7A. As a consequence of this, the available electricity from biogas will be considerably higher in all cases, with regard to the variants previously analysed for saturated steam. In the low value, a good electricity generation by biogas (86.62%) and surpluses in the medium (164.05%) and high (283.48%) values are achieved.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Low value</th>
<th>Medium value</th>
<th>High value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Steam pressure at turbo inlet</td>
<td>17.56</td>
<td>17.56</td>
<td>17.56</td>
<td>bar abs</td>
</tr>
<tr>
<td>2 Exhaust pressure at turbo outlet</td>
<td>2.05</td>
<td>2.05</td>
<td>2.05</td>
<td>bar abs</td>
</tr>
<tr>
<td>3 Steam temp. at turbo inlet</td>
<td>310.00</td>
<td>310.00</td>
<td>310.00</td>
<td>ºC</td>
</tr>
<tr>
<td>5 Steam rate of turbo generator</td>
<td>11.98</td>
<td>11.98</td>
<td>11.98</td>
<td>kg/kW-h</td>
</tr>
<tr>
<td>6 Electrical demand standard as in Estévez (2007b)</td>
<td>17.33</td>
<td>17.33</td>
<td>17.33</td>
<td>kW-h/hL</td>
</tr>
<tr>
<td>7 Available electricity from biogas</td>
<td>312.70</td>
<td>592.23</td>
<td>1023.38</td>
<td>kW</td>
</tr>
<tr>
<td>8 Electricity demanded by distillery</td>
<td>361.01</td>
<td>361.01</td>
<td>361.01</td>
<td>kW</td>
</tr>
<tr>
<td>9 Electricity generation by biogas</td>
<td>86.62</td>
<td>164.05</td>
<td>283.48</td>
<td>%</td>
</tr>
</tbody>
</table>

It can be concluded that steam and electricity generation by biogas could be significantly beneficial for both levels of steam parameters studied, with the characteristic that there will be more steam generation by biogas in the variant at 11.35 bar abs (saturated steam) than at 18.25 bar abs and 330ºC (superheated steam). However, in this last alternative, there is more electricity generation by biogas than the first one. A particular study would help to decide the selected alternative. It is necessary to point out that steam generation in excess of the distillery demand has no practical sense in the analysed conditions. In this circumstance, biogas could be stored.

Elimination of hydrogen sulfide H$_2$S from biogas (Desulphurisation)

As was shown in Table 4, there is always significant sulfur content in the form of H$_2$S in produced biogas. The use of biogas directly as a fuel in steam boilers without purification has resulted in serious corrosion problems, which have led to failures such as in eco-efficiency for Australian dairy processors (2004). Therefore, in order to be able to use the biogas as fuel in steam boilers, it is necessary to carry out a desulphurisation process.

The commonly used desulphurisation processes, in general, can be classified in two categories, that is: (A) Desulphurisation in dry and (B) Desulphurisation in liquid phase.

(A) Dry Desulphurisation as in Kapdi (2004) is often used in homemade productions. This paper is related only to industrial productions.

(B) Desulphurisation in liquid phase.

One solution for H$_2$S removal in liquid phase is a commercial technology called Greenlane of FLOTECH as in www.flotech.com (2006). The raw biogas under pressure enters a scrubber through the bottom, making contact with water in a counter flow process, and the clean gas goes to an outlet at the top part. The CO$_2$ and H$_2$S are absorbed by the water.

Other processes frequently used for removal of H$_2$S consist of scrubbing of biogas with an alkaline solution. In the references are:

- The use of hydrated lime as in Marchaim (1992) in solid or liquid form. This substance has not been applied on a great scale for a long time, because of the big quantity of residuals with bad smell that occur and that cannot be eliminated satisfactorily. Big concentrations of CO$_2$ that are present in biogas composition make
the satisfactory removal of H$_2$S difficult, since the CO$_2$ also reacts with the live or hydrated lime. Of course, the elimination of CO$_2$ is also convenient for using biogas as fuel. For this reason, this desulphurisation process could be considered if:

- Limestone is available in the market.
- When the residuals destination from the process is very secure.

- *Use of NaOH.* In a commercial system called THIOPAQ as in www.sta-at.com, NaOH is described as a washer or scrubber for biogas desulphurisation. The NaOH consumed in absorption of H$_2$S is continually regenerated in a bioreactor (biological method). The absorption of H$_2$S inside the scrubber is given under basic conditions. The washer liquid that contains the extracted sulfur of H$_2$S is transferred to the bioreactor where this sulfur is oxidised to elementary sulfur by use of a series of bacteria.

- *Using ferric solutions or ferric salts as ferric chloride.* There is a commercial system from Eco-Tec as in www.eco-tec.com BgPurTM or cleanser of the biogas, which is based on a high effectiveness device of contact gas-liquid. The scrubber or cleanser removes the H$_2$S from a current of gas using a purifying solution that uses a very well-known ferric chemical reducer. The vessel for regeneration of the polluted purifying solution uses atmospheric oxygen to convert H$_2$S to elementary sulfur. The regenerated solution, now free of H$_2$S, is returned to the cleanser vessel. The catalyst, the products of the reaction, and the preservative buffer are all acceptable environmentally.

- *Novel patent of Habets (1999).* The natural alkalinity generated during aerobic biological processes for purification of waste waters, i.e. a biomass carrier, can be used as washer instead of adding some alkaline chemical products. The aerobic treatment of the waste waters, which has an acquired alkalinity in a natural way, contacts the biogas that contains H$_2$S. The H$_2$S will be absorbed from the biogas in a water phase. The advantage of this treatment is that some chemical product is not added; therefore, the operational costs are low. An additional advantage is that the washer liquid which, at the end of process, contains the absorbed H$_2$S, can be recycled toward the aerobic treatment without difficulty and without some additional treatment. The scrubbing liquid that contains the extracted sulfur of the hydrogen sulfide is transferred to a bioreactor, where this sulfur is oxidised until elementary sulfur due to a series of bacteria.

**Conclusions**

**Steam and electricity generation with the biogas production**

The non-harvest season period was analysed because of the non-availability of bagasse as fuel. The generated energy by biogas was calculated by a program using Excel applied to a distillery example of 50 000 L/d. Steam and electricity balances were carried out for two levels of steam generation parameters: 11.35 bar abs saturated steam and 18.25 bar abs and 330ºC superheated steam. It was calculated for a medium value and extreme high and low values.

**Steam generation**

For the generation at 11.35 bar abs (steam saturated), the steam available is highly significant since, in the low value, there was an important steam generation by biogas of 69.34% of steam demanded and a wide surplus for the medium (131%) and high values (226.94%).

For 18.25 bar abs and 330ºC, an important steam generation by biogas of 61.16% for the low value with regard to steam demanded by the distillery and a large surplus in the medium (115.84%) and high (200.16%) values, although not as high as the previous case of saturated steam.
Electricity generation

For generation at 11.35 bar abs (steam saturated), the available electricity was significant since, for the low value, there was an electricity production by biogas of 56.02% of the demand and a large surplus in the medium (106.11%) and high (183.3%) values.

For 18.25 bar abs and 330ºC, more electricity was produced by biogas. In the low value, there was a good electricity generation by biogas (86.62%) and surpluses in the medium (164.05%) and high (283.48%) values.

It can be concluded that steam and electricity generation by biogas could be significantly beneficial for both levels of steam parameters studied, with the characteristic that there will be more steam generation by biogas in the variant at 11.35 bar abs (saturated steam) than at 18.25 bar abs and 330ºC (superheated steam) although, in this last alternative, there is more electricity generation by biogas than the first one.

Biogas desulfurisation systems that would be of use in ethanol distilleries offered for industrial scale presented here:


This system uses under pressure biogas at counter flow with water (It does not use chemical products) with a later recovery system for the same water using atmospheric air.

**Use of hydrated lime as in Marchaim (1992)**

This is in solid, or in liquid form. This means besides the H₂S, the CO₂ is also eliminated in biogas which is also convenient, provided that limestone is available and there are reliable means of disposing of the residuals with bad smell.

**System THIOPAQ of STA-AT as in [www.sta-at.com](http://www.sta-at.com)**

The biogas enters in a washer with a liquid that contains caustic soda that absorbs H₂S. For regeneration of the scrubber liquid, this is transferred to a bioreactor, where the sulfur is oxidised thanks to a series of bacteria.

**System BgPurTM of Echo-Tec as in [www.eco-tec.com](http://www.eco-tec.com)**

The washer removes the H₂S using a watery solution for scrubbing with a very well-known ferric reducing substance. For regeneration of the washer solution, atmospheric oxygen is used which converts H₂S to elementary sulfur.

**Novel patent of Habets (1999)**

The natural alkalinity generated during an aerobic biological process for purification of waste waters; carrier of biomass, can be used as washer instead of addition of alkaline chemical products; therefore operational costs are low. Washer liquid, the one that contain the absorbed H₂S, can be recycled toward the aerobic treatment without difficulty and without some additional treatment.

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BILAN ÉNERGIE DURABLE POUR LES DISTILLERIES D'ÉTHANOL

Par

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MOTS-CLÉS: Traitement de Vinassee, Production de Biogaz, Biogaz de Vinassee.

Résumé
LA PRODUCTION d'éthanol à partir des substrats contenant du sucre génère des eaux usées provenant de la partie inférieure de tours de distillation, connues comme la vinasse. Celle-ci constitue le plus fort polluant du procédé industriel. À l'aide d'un groupe de paramètres sélectionnés dans une large gamme de références internationales, le présent document comporte des bilans d'énergie (vapeur et électricité) pour démontrer à l'aide d'Excel que du biogaz produit à partir de la digestion anaérobie de ce polluant, en outre de la dégradation de la vinasse, peut contribuer à satisfaire la demande d'énergie d'une distillerie d'éthanol. Les résultats sont présentés pour des concentrations de vinasse à taux faible, moyen et élevé. L'étude vise également à utiliser cette énergie pour alimenter les chaudières conventionnelles à vapeur, tout en supprimant le sulfite d’hydrogène contenu dans le biogaz par un procédé appelé desulfurisation. À cette fin, les meilleures méthodes pour desulfurer ce gaz combustible, sont recommandées.

ENERGÉTICA SOSTENIBLE PARA DESTILERÍAS DE ETANOL

Por

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PALABRAS CLAVE: Tratamiento de Vinazas, Producción de Biogas, Biogaz de Vinazas.

Resumen
LA PRODUCCIÓN de etanol a partir de materias primas azucaradas genera aguas residuales del fondo de las columnas de destilación, bien conocidas como vinazas. Éstas constituyen la mayor carga contaminante. El presente trabajo, empleando un grupo de parámetros hallados en la larga lista de referencias internacionales, muestra balances de energía (de vapor y electricidad) empleando Excel, para demostrar que el biogas producido de la digestión anaeróbica de esta carga contaminante, además de degradar las vinazas puede contribuir a abastecer las demandas de energía de una destilería de etanol. Los resultados se presentan para medianos, bajos y altos niveles valores de concentración de polutante. Se intenta, igualmente, emplear la energía para alimentar quemadores de gas en calderas de vapor convencionales, removiendo el H2S que contiene el biogas, por un proceso denominado desulfurización. Finalmente se recomiendan los mejores métodos para desulfurar este gas combustible.
THE COLOMBIAN EXPERIENCE IN THE PRODUCTION OF BIOETHANOL FOR TRANSPORT USE

By

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KEYWORDS: Sucro-Chemistry, Sugar Derivatives, Alcohol Industry, Vinasse, Bioethanol.

Abstract

THE NATIONAL Colombian Program for promoting the use of oxygenated gasoline for transport purposes started in 2001 with the implementation of the governmental tax incentives and the definition of the required technical framework for blending and fuel quality. The maximum level of blend for ethanol and gasoline was determined to be 10% v/v and the minimum concentration of dehydrated ethanol 99.5% v/v. Since 2005, five ethanol plants, using sugarcane feedstocks, are operating in the country with an overall production of 1 050 000 litres/day. The technological configuration of all plants is alike, mainly conformed by a continuous fermentation section and a continuous ethanol dehydration section. This paper describes some specific features derived from the commencement of the plants and some problems found in the normal operation of the fermentation. These troubles are mainly related to persistent microbial contamination in the fermentors, which reduces ethanol production efficiency and causes an overproduction of toxic and inhibitor organic compounds like acetic acid and lactic acid, among others. From a monitoring campaign, it was established that each plant had to develop its own adaptation process, such as the usage of different feedstock blending relationships, and to follow different learning curves despite the common technology used.

Introduction

In the past 5 to 6 years, the acknowledgment and acceptance of ethanol as an oxygenating additive for fuels commonly used in automobiles have extended beyond the United States and Brazil, the countries with the highest production and consumption. As a result, different evaluative, legislative, economic, and research activities have been conducted in several countries of Asia, Africa, Europe, and Latin America, as well as Australia, to promote and expand the use of ethanol as a fuel (Shete, 2003).

The production of ethanol and the establishment of new alcohol production plants, or the expansion of existing plants, are important issues for the sugar and sucro-chemical sectors of the department of Valle del Cauca, Colombia, to satisfy the needs for oxygenating compounds or gasoline additives.

Plans, therefore, include the study and search for strategies that reduce the environmental impact of sugar industry effluents, commonly known as vinasses, the main by-product of the alcohol-chemical industry. It is therefore indispensable to have a good diagnosis and characterisation of vinasses in our national scenario.

In the Colombian alcohol-chemical industry, sugarcane molasses is currently used as the substratum and the yeast Saccharomyces cerevisae as the biological catalyst. Vinasse is a high-volume by-product, generated at a ratio of 14 litres per litre alcohol produced.
During production, vinasse is characterised by its high temperature, low pH (4.2–4.6), and high content of suspended, dissolved organic matter. Vinasse also contains a considerable number of inorganic salts (sulfates, phosphates, etc.), calcium, potassium, sodium, magnesium (0.1%–4.4% in concentrated vinasse), and other elements in smaller amounts (6–300 ppm) (Briceño, 2006).

Vinasse has been broadly used in agriculture because it improves almost all soil fertility factors. In Brazil, because of prevailing soil conditions, vinasse is used as an organic fertiliser either alone or mixed with other products, depending on the specific characteristics of each region. In Colombia, however, rates above 50 m³ per hectare are not applied. Although the high organic matter content of vinasse justifies its use as fertiliser, this characteristic should be given special attention when considering new uses of this byproduct. The possibility of extracting organic compounds of high added value should also be studied (Graca, 2002).

In Colombia, ethanol production for transport started in October 2005. Table 1 summarises the capacities and starting date of each Colombian plant. By July 2009, the demand coverage of ethanol reached 85% to supply the biofuel just to the northern portion of the country.

Bioethanol projects and investments in Colombia

Over the last decade, technical, economic, and environmental studies have been conducted in Colombia to determine the feasibility of the country entering the ‘bioethanol era’. As a result, several requests for clarification on legal and commercial issues have been presented before the national and departmental governments. The national program that has been established offers the opportunity to address the following sectors and topics:

- Farmers growing cane, maize, cassava, sweet sorghum, potato, and beet.
- Engineering and construction firms, installers, environmentalists, and transporters.
- Effective reduction of CO₂ emissions.
- Opening to biofuels and alcohol chemistry.
- Legal precautions for private investors.
- Sound legislation and regulations in related technical and environmental issues and regarding prices.
- Tax-related incentives (VAT, tax on gross revenue, and surcharge).

Colombia’s national fuel alcohol program aims to produce ethanol from sugarcane and other agricultural inputs to improve the quality of gasoline. Legislation favouring this undertaking includes the following:

- Law 788 of 2002 exempts fuel alcohol from the payment of taxes normally charged on gasoline such as the tax on gross revenue, VAT, and surcharge (Articles 31 and 88).
- The Ministry of Environment, Housing, and Territorial Development, together with the Ministry of Mines and Energy, passed Resolution 0447 of 2003 to regulate quality characteristics of alcohol and oxygenated gasoline and to establish the minimum percentage of anhydrous alcohol (99.5%).
- The Ministry of Mines and Energy, by Resolution 181710 of 23 December 2003, established that the ceiling price would be established and then adjusted annually as follows: 70% based on the variation of the Producer Price Index (PPI) and the remaining 30% based on the annual devaluation.
In Colombia, the main clients of oil refineries are large distributors that store and re-distribute fuels (petroleum derivatives) to smaller suppliers or clients, who, in turn, sell the product to typical users (citizens). This scheme will continue in the case of alcohol and gasoline mixtures. Each country must not only establish its own product specifications but also define how and where the mixtures are prepared, and how they are dispatched and received. The safety controls to minimise risks, ensure quality, and prevent losses or alterations vary depending on the methods and technologies involved. Figures 1 and 2 present a summarised scheme of the main factors related to important clients of distilleries (Calero et al., 2003).

![Diagram showing factors associated with the reception, mixture, and distribution of gasoline and alcohol that affect the businesses of important clients or distributors.](image)

**Fig. 1**—Factors associated with the reception, mixture, and distribution of gasoline and alcohol that affect the businesses of important clients or distributors.

Figure 2 schematically shows the system of preparing and distributing gasoline-fuel alcohol mixture (10%), adopted in Colombia.

![Diagram of the system of mixing and distributing gasoline-fuel alcohol mixture (10%) in Colombia.](image)

**Fig. 2**—System of mixing and distributing gasoline-alcohol fuel (10%) mixtures in Colombia.

**Bioethanol projects and investments in Colombia**

The production of bioethanol as an oxygenating additive for gasoline began in Colombia in October 2005 and, to date, there are five distilleries adjunct to sugar refineries (Table 1).
The building and putting into operation of these new processing plants in the geographical valley of the Cauca River implied the compliance of numerous environmental, technical, legal, commercial, and financial requirements. The factors found to have greater impact on ethanol production projects were the raw material and its permanent availability, the technology used (fermentation, dehydration, effluent concentration and treatment, etc), the effluents produced, energy requirements, automation, and capital costs.

**Table 1**—Bioethanol production of different cane sugar mills in Colombia.

<table>
<thead>
<tr>
<th>Cane sugar mill</th>
<th>Bioethanol production (L/day)</th>
<th>Starting date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mayagüez</td>
<td>150 000</td>
<td>March 11, 2006</td>
</tr>
<tr>
<td>Providencia</td>
<td>250 000</td>
<td>October 26, 2005</td>
</tr>
<tr>
<td>Risaralda</td>
<td>100 000</td>
<td>March 11, 2006</td>
</tr>
<tr>
<td>Manueita</td>
<td>250 000</td>
<td>March 24, 2006</td>
</tr>
<tr>
<td>Incauca</td>
<td>300 000</td>
<td>October 27, 2005</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1 050 000</strong></td>
<td></td>
</tr>
</tbody>
</table>


The investors in new alcohol production plants should assess the opportunities that will arise with the increasing demand for the product worldwide as well as the competition between technologies, raw materials, effluent treatments, development of derivatives/byproducts and reduced investment costs, processes and quality.

In Colombia, the five recently established distilleries are adjunct to cane sugar mills and use technology of Praj and Delta T, with vinasse concentration and its subsequent use to obtain compost (see text boxes 1 and 2, Figures 3 and 4).
Fig. 3—Typical milling flow chart for sugar production in Colombia. Source: Vivas, A.L. (2006).

ATR = Azúcar Total Recuperable (as original) (Total Recoverable Sugar).

Fig. 4—Typical flow chart for ethanol production in Colombia.
Relevant features of the actual Colombian technology

The distilleries coupled to sugarcane mills in general use molasses B, with a recirculation system for vinasse. All plants are operating with continuous fermentation, distillation and dehydration process.

The distillation step has two units. From the first one, ethanol at 45% is obtained and from the second, ethanol at 95% is produced followed by the dehydration step. All bioethanol plants are using a strain from the yeast *Saccharomyces cerevisae* as the biological catalyst, provided by Praj - Delta T Company.

To establish some indicators or parameters which can indicate the performance of the whole fermentation stage, a monitoring campaign was conducted for determining glycerol and organic acids concentration levels (lactic, acetic and butyric) during a steady state operation period of the plant. Then, during an abnormal and atypical operational condition of the fermentors, the same concentration levels were measured, in order to establish any possible relationship between microbial contamination and inhibitors formation. Other operational conditions at the fermentors such as temperature and pH were kept constant. It must be noted that an abnormal condition situation was promoted by the continuous operation of the plant with no scheduled addition of any microbiological or chemical agent.

The plant uses two continuous fermentors with 8-hours-retention-time each one. Vinasse was recycled to first and second fermentor. Samples for analytical chemical and microbiological tests were collected from global entering and exiting streams from both fermentors. Additional samples were collected too from the wine tank. Determinations of selected organic compounds were carried out at Cenicãña’s lab using HPLC technique. Microbiological analysis uses plate count method. Each monitoring record included three samples of each location.

It was found during the stable or normal operation of the fermentation, that concentration levels of organic compounds were on average lower than 0.6% w/w, while during the atypical stages those reached in average 0.75% w/w (Figures 5 and 6). So, an important increase of 33% of total organic acids content during periods of higher microbial contamination can be reported, which can affect the fermentation process and ethanol production. Also, for glycerol, increases of 3 to 11% were found in its w/w concentration during atypical operation. Population of Lactic Acid Bacteria (LAB) was higher during the atypical operation (> 2x10⁶ CFU/mL) compared with the levels observed for stable operation (< 8x10⁵ CFU/mL).

![Fig. 5—Organic acids content in a fermentation stage during two different reactor conditions (lactic, acetic and butyric acids).](image-url)
In a parallel way, a second monitoring campaign was conducted in a different distillery for assessing the mass and energy balance of the whole plant. It was observed that the ethanol plant produces different vinasse-ethanol ratios mainly explained for the quality of the substrate mixtures supplied to the fermenter. So, it can be established that the mixture of clarified juice-molasses B used as feedstock to the fermenter produced less volume of vinasse per ethanol volume (Figure 7).

**Figure 6**—Glycerol content in a fermentation stage during two different reactor conditions.

**Figure 7**—Vinasse volume per anhydride ethanol produced for several substrates employed during continuous fermentation. (MB = Molasses B; S/MB = Syrup/Molasses B relationship).

It can be noted that some comments on the performance of the selected technological scheme for ethanol plants in Colombia are focused on often recurrent operational problems caused by microbiological contamination by wild yeast and other micro-organisms, such as lactobacillus. In order to establish a biological control for wild yeast or other kinds of micro-organism, further studies are underway which include a biological characterisation of the different strains which might affect ethanol production.

**Conclusions**

- In medium-term investments, the producer of fuel alcohol should consider aspects ranging from environmental permits granted by the State to commitments with companies responsible for the gasoline mixtures.
• The main use of bioethanol in Colombia is currently as a fuel oxygenating additive; however, a very broad range of derivatives or byproducts exists, all with significant market demand.

• The periodic evaluation of organic acids and glycerol concentration levels can be useful for getting a potential biochemical marker which can be a performance index of the fermentation process.

• Some operational problems arise during the production of bioethanol in Colombia, mainly related with microbiological contamination with wild yeast, causing the need for a new operational approach to the sugar plant.

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http://www.gea-phe.com/themes/applications/renewable-energies/


liées à la contamination microbienne persistante dans les fermentateurs, qui réduisent les rendements de production d'éthanol et entraîne une production de composés toxiques et d'inhibiteurs organiques tels que l'acide acétique et acide lactique. À partir d'une campagne de suivi, il a été établi que chaque usine devait développer sa propre stratégie, telle que l'utilisation de différentes matières premières en mélange, et de suivre différentes courbes d'apprentissage malgré que la technologie soit communément en utilisation.

LA EXPERIENCIA COLOMBIANA EN LA PRODUCCIÓN DE BIOETANOL PARA USO EN TRANSPORTE

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PALABRAS CLAVE: Sucroquímica, Derivados del Azúcar, Industria Alcoholera, Vinazas, Bioetanol.

Resumen
EL PROGRAMA Nacional Colombiano para promover el empleo de gasolinas oxigenadas para propósitos de transporte comenzó en el 2001 con la implementación de incentivos gubernamentales de impuestos y la definición del marco técnico requerido para la mezcla y calidad de los combustibles. El máximo nivel de mezcla etanol - gasolina se determinó que era 10% v/v y la mínima concentración de etanol deshidratado 99.5%. Desde el 2005 operan en el país cinco plantas de etanol, empleando caña de azúcar como materia prima, con una producción total de 1 050 000 litros/día. La configuración tecnológica de todas las plantas son similares, conformada básicamente por una sección de fermentación continua y una sección continua de deshidratación de etanol. Este trabajo describe algunos aspectos específicos derivados de la arrancada de las plantas y algunos problemas encontrados en la operación normal de la fermentación. Estos problemas están básicamente relacionados con una contaminación persistente en los fermentadores, que reducen la eficiencia de la producción de etanol y causan sobreproducción de componentes orgánicos tóxicos e inhibidores, tales como los ácidos acético y láctico, entre otros. A partir de una campaña de monitoreo, se estableció que cada planta debe elaborar su propio proceso de adaptación, tales como el empleo de diferentes relaciones de mezcla de materias primas y seguir diferentes perfiles de desarrollo y adaptación con independencia de la tecnología común empleada.
TECHNO-ECONOMIC INDICATORS FOR THE THERMOCHEMICAL AND BIOCHEMICAL ROUTES FOR BIOFUELS PRODUCTION USING SUGARCANE BAGASSE AS FEEDSTOCK

By

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KEYWORDS: Second Generation Biofuels, Sugarcane Bagasse, Biochemical Route, Thermochemical Route.

Abstract

The main goal of the paper is to compare the biochemical and thermochemical routes for second generation biofuels production performance, using efficiency and economic indicators. In both cases, the feedstock used is bagasse. Calculations are carried out for a biofuel plant having a bagasse consumption of 1772 t/day of dry matter, equivalent to 400 MW of thermal energy. By-products utilisation, such as lignin in the biochemical route, and bagasse for steam and electricity self sufficiency through cogeneration were considered also. The high production cost of bioethanol obtained through the biochemical route (21.32 to 22.7 US$/GJ$_{ETOH}$) is strongly influenced by the enzyme costs. The biomethanol production cost by the thermochemical route (15.82 US$/GJ$_{MeOH}$) is mainly influenced by the high equipment cost.

Introduction

Biofuels derived from lignocellulosic biomass can be produced through two conversion routes: the biochemical and thermochemical ones, and are classified as second generation biofuels to differentiate them from the conventional first generation ones.

The production of ethanol through pre-treatment, hydrolysis and fermentation from the sugars resulting from lignocellulosic materials conversion corresponds to the biochemical conversion route. On the other side, the obtainment of biofuels derived from biomass gasification synthesis gas conversion (Fischer-Tropsch liquids, methanol synthetic natural gas – SNG, and other hydrocarbons) corresponds to the thermochemical conversion route Schwietzke et al. (2008).

Presently, the bioethanol production cost from lignocellulose is high, and this is the main reason it has not reached the market commercialisation stage. Sassner et al. (2008) presented the results of the techno-economic evaluation of bioethanol production from three types of lignocellulosic materials, and showed production costs in the range from 0.66 to 0.87 US$/L, depending of the feedstock used. Finally, according to a study carried out by the United States Energy Department (DOE, 2008), the bioethanol cost can be reduced to the range 0.3–0.4 US$/L in the future.

Regarding methanol, although great environmental restrictions exist regarding its utilisation due to the mainly fossil origin, a considerable number of techno-economic evaluations based on its production through renewable non-commercial technologies have been reported. The use of the renewable methanol could increase the sustainability of biodiesel production considerably, raising the output/input relation (renewable to fossil energy relation) of this process from 5 to 8, reaching the same value as for conventional ethanol, as reported by Angarita et al. (2009).
According to Hamelick and Faaij (2001), the average biomethanol production cost varies between US$9 – 12/GJ for a plant with a processing capacity of 400 MW (biomass feedstock cost is 2 US$/GJ).

Lower production costs, of about 8.04 US$/GJ also for a 400 MW plant (biomass feedstock cost of 2 US$/GJ), can be reached when the technology LPMeOH™ (Liquid Phase Methanol) is used, as work of Sørensen (2005).

In this paper, the biochemical and thermochemical routes for the production of second generation biofuels (bioethanol and biomethanol respectively), using sugarcane bagasse as feedstock are compared using different techno-economic indicators.

Feedstock

Lignocellulosic biomass is composed mainly of carbohydrates (cellulose and hemicelluloses), lignin and a small fraction of extractives, acids, salts and minerals, as reported by Hamelinck et al. (2005) and Mosier et al. (2005).

Sugarcane bagasse and trash are co-products of the sugar and ethanol industry. In the harvest 2007/2008, the Brazilian sugar and alcohol agro-industry, having approximately 300 mills, processed 4.32x10^8 tonnes of cane for the production of 2.0x10^7 m³ of ethanol. The quantity of sugarcane processed generated about 1.2x10^8 tonnes of bagasse (UDOP, 2009).

Therefore, a wide recognition exists that the annual production of cane bagasse reaches huge figures and that the efficient use of this residue is an urgent necessity, with wide potential for the development of more profitable activities than direct combustion or gasification for electricity generation, and biofuels production, as discussed by Pitarelo (2007). It is assumed that both the bioethanol and biomethanol plants are located in Brazil, are autonomous, and have a processing capacity of 400 MWth (1772 t/day of dry biomass). Bagasse is acquired from nearby sugar and alcohol mills at market prices.

Biochemical platform

Process description

The process of bioethanol production starting from lignocellulosic materials has the following stages: pre-treatment of the raw material, hydrolysis, fermentation and distillation (Figure 1). Also, a stage of steam and power generation by using the solid residues of the process as fuel should be considered.

![Flowchart of bioethanol from biomass production (Hamelinck et al., 2005).](image-url)

In the bioethanol plant, bagasse does not require previous grinding due to its small size distribution, and it is assumed to have 50% moisture. The bagasse is imbued with gaseous SO₂ that functions as a catalyst for the pre-treatment process (Sendelius, 2005). The bagasse pre-treatment is carried out in a reactor, where steam with a pressure of 400 kPa is injected. A sudden system decompression is carried out and the slurry is collected in an expansion tank.
After this, comes the proper hydrolysis process using enzymes, where two types of sugar are produced: C6 (glucose) and C5 (non-glucose-xylose). It must be taken into account that conventional yeast can not ferment C5 sugars. Before the hydrolysis, the pH of the pretreated bagasse should be adjusted by the addition of sodium hydroxide.

For sugars fermentation, two technologies are considered: the simultaneous saccharification and fermentation (SSF) and the simultaneous saccharification and co-fermentation (SSCF). In the case of the SSF hydrolysis (Table 1), only the fermentation of C6 sugars is considered. It is assumed that conventional *Saccharomyces cerevisiae* yeasts are used and that these are produced *in situ*, while enzymes are acquired from specialised suppliers.

In the case of SSCF hydrolysis, it is assumed that the yeasts used are genetically modified and they are capable of fermenting both C6 and C5 sugars (Table 1). However, presently, these yeasts do not reach yields shown in Table 1, and they are being used only in laboratory scale (Öhgren, *et al.*, 2006).

### Table 1—Main parameters and stages yields assumed for the modelling of the two selected systems for ethanol production from lignocellulose.

<table>
<thead>
<tr>
<th>Technology</th>
<th>SSF</th>
<th>SSCF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass input</td>
<td>400 MWth</td>
<td>400 MWth</td>
</tr>
<tr>
<td></td>
<td>1772 t&lt;sub&gt;in&lt;/sub&gt;/day</td>
<td>1772 t&lt;sub&gt;in&lt;/sub&gt;/day</td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>Catalysed steam explosion</td>
<td>Catalysed steam explosion</td>
</tr>
<tr>
<td>Biomass moisture (%)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Catalysis (kg SO&lt;sub&gt;2&lt;/sub&gt;/kg based on wet bagasse)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Cellulose recuperation (%)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>96.3</td>
<td>96.3</td>
</tr>
<tr>
<td>Hemicellulose recuperation (%)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>51.9</td>
<td>51.9</td>
</tr>
<tr>
<td>Hydrolysis and Fermentation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enzymatic load (FPU/g cellulose)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Cellulose hydrolysis (kg glucose/kg cellulose)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.85</td>
<td>0.85</td>
</tr>
<tr>
<td>Fermenting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glucose (%)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>90 – 95</td>
<td>90 – 95</td>
</tr>
<tr>
<td>Xylose (%)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>80 – 92</td>
<td>80 – 90</td>
</tr>
<tr>
<td>Required power (MWe)&lt;sup&gt;d&lt;/sup&gt;</td>
<td>3.76</td>
<td>3.52</td>
</tr>
<tr>
<td>Required steam&lt;sup&gt;e&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-treatment (kg/kg bagasse&lt;sub&gt;dry&lt;/sub&gt;)</td>
<td>0.2 (400 kPa)</td>
<td>0.2 (400 kPa)</td>
</tr>
<tr>
<td>Drying of the centrifugated lignin (t/twe)</td>
<td>1.01 (1100 kPa)</td>
<td>1.01 (1100 kPa)</td>
</tr>
<tr>
<td>Distillation (kg/kg produced ethanol)</td>
<td>2.57 (400 kPa)</td>
<td>1.03 (400 kPa)</td>
</tr>
</tbody>
</table>

<sup>a</sup> Macedo, 2008.
<sup>b</sup> Sendelius, 2005. FPU (Filter Paper Units)
<sup>c</sup> Hamelinck *et al.*, 2005.
<sup>d</sup> The required power for different process stages was estimated according to Wooley *et al.* (1999).

In the hydrolysis stage, 96.3% of the cellulose is recovered. A performance of bioethanol production of 76.89% of the theoretical value is assumed to be achieved starting from glucose (Sendelius, 2005).

The bioethanol is concentrated up to 92.5% on a distillation stage that consists of two columns, the first being an exhaustion column, and the second a rectification one, and operating on different pressures. After this, the bioethanol is concentrated up to 99.5% of purity through a molecular sieve process. A scrubber is used to minimise the bioethanol losses with the CO<sub>2</sub> vent from fermentation.
From the bottom of the rectification column, the co-products of the distillation stage mixed with the residual lignin are recovered. Lignin is separated by centrifugation and dried in a steam dryer up to moisture of 48%, before being supplied to the boiler, to be used as fuel for cogeneration.

The recovered lignin is burned in a boiler that produces 127.08 t/h of steam for electricity production in steam turbines. The isentropic efficiency of the turbine was assumed to be 0.85, while the generator efficiency was 0.925. The lignin low heating value (LHV) in dry basis was considered to be 17.5 MJ/kg (Bensen et al., 2006).

Thermochemical platform

Process description

In Figure 2, the general outline of the evaluated process is shown. For this case study, a pressurised bubbling fluidised bed gasifier, that uses a mixture of oxygen and steam as the gasification agent, was chosen. In Table 2, the main gasifier parameters are shown (Tijmensen, 2000).

Once the cane bagasse arrives at the plant with moisture of 50%, it is necessary to dry it until it reaches the specifications requested by the gasification process, about 20% (Tijmensen, 2000).

![Flowchart of biomethanol from biomass production](image)

**Table 2—Main parameters of the gasification process.**

<table>
<thead>
<tr>
<th>Gasification parameters</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Relation [(steam+oxygen)/biomass) (kg/kg)</td>
<td>0.6</td>
</tr>
<tr>
<td>Bed temperature (K)</td>
<td>1173</td>
</tr>
<tr>
<td>Pressure (Pa)</td>
<td>3039.75</td>
</tr>
<tr>
<td>Biomass moisture (%)</td>
<td>20</td>
</tr>
<tr>
<td>Gas yield (kmol/dry tonne)</td>
<td>82</td>
</tr>
</tbody>
</table>

*Hamelinck and Faaij, 2001*

The gas produced contains tar, dust, alkalis and halogens that can affect the catalysts used in downstream processes. Particles removal from the gas is carried out using cyclones, fabric filters and scrubbers. A HRSG (heat recovery steam generator) is used for gas cooling.

The gas produced has a considerable amount of methane and other light hydrocarbons. A steam reforming stage is included to maximise the concentration of CO and H\textsubscript{2} by the conversion of CH\textsubscript{4} and C\textsubscript{2}H\textsubscript{6}. The H\textsubscript{2}/CO relation of the syngas is adjusted through the gas-water shift reaction (WGS). The synthesis gas passes through a CO\textsubscript{2} removal stage and enters the reactor of methanol synthesis. Finally, the raw gas obtained from the synthesis goes through a purification stage to obtain the biomethanol with the necessary purity (Ohlström, et al., 2001).
Economic analysis

Relevant parameters assumed during ethanol production cost calculations are given in Table 3.

Table 3—Parameters for the economic evaluation.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>The economical lifetime ($t_e$)</td>
<td>15 years Assumed</td>
</tr>
<tr>
<td>The technical lifetime ($t_t$)</td>
<td>25 years Assumed</td>
</tr>
<tr>
<td>Interest rate ($IR$)</td>
<td>10% Assumed</td>
</tr>
<tr>
<td>Exchange rate</td>
<td>$1\ US$ = 2.2972\ R$ 14/10/2008</td>
</tr>
<tr>
<td>Bagasse price</td>
<td>10.9\ US$/t_{(wet\ base)}</td>
</tr>
<tr>
<td>Enzymes cost</td>
<td>0.32 US$/L_{ETOH}</td>
</tr>
<tr>
<td>Electricity commercialisation price</td>
<td>50 US$/MWh</td>
</tr>
</tbody>
</table>

The total capital investment, or TCI, is calculated using an estimated scale factor based on known costs for major equipment as found in literature and/or given by experts (Tables 4 and 5). Operational costs (maintenance, labour, consumables, residual streams disposal) are taken as a single overall percentage (4%) of the total investment.

Table 4—Costs of the bioethanol system components in MUS$ _{2008}$.

<table>
<thead>
<tr>
<th>Component</th>
<th>Base investment costs</th>
<th>Scaling Factor</th>
<th>Base Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Handling and feeding</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conveyors $^a$</td>
<td>0.19</td>
<td>0.76</td>
<td>160 $t_{(wet\ base)}/h$</td>
</tr>
<tr>
<td>Feeding system $^a$</td>
<td>0.0081</td>
<td>0.76</td>
<td>160 $t_{(wet\ base)}/h$</td>
</tr>
<tr>
<td>Pre-treatment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steam Explosion $^b$</td>
<td>1.48</td>
<td>83.3 $t_{(dry\ base)}/h$</td>
<td></td>
</tr>
<tr>
<td>Hydrolysis and Fermentation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reactors SSF $^a$</td>
<td>3.02</td>
<td>0.8</td>
<td>17.65 t ethanol/h</td>
</tr>
<tr>
<td>Reactors SSFC $^a$</td>
<td>3.02</td>
<td>0.8</td>
<td>17.65 t ethanol/h</td>
</tr>
<tr>
<td>Seed unit production $^a$</td>
<td>0.79</td>
<td>0.6</td>
<td>17.65 t ethanol/h</td>
</tr>
<tr>
<td>Distillation and purification</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Column distillation 1 $^b$</td>
<td>1.04</td>
<td>0.7</td>
<td>18.47 t ethanol/h</td>
</tr>
<tr>
<td>Column distillation 2 $^b$</td>
<td>0.90</td>
<td>0.7</td>
<td>18.47 t ethanol/h</td>
</tr>
<tr>
<td>Molecular sieve $^b$</td>
<td>2.80</td>
<td>0.7</td>
<td>18.47 t ethanol/h</td>
</tr>
<tr>
<td>Lignin recuperation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dryer $^c$</td>
<td>0.074</td>
<td>0.76</td>
<td>184 m$^3$</td>
</tr>
<tr>
<td>Power and steam generation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boiler $^c$</td>
<td>2.79</td>
<td>0.76</td>
<td>187,200 kg steam/h</td>
</tr>
<tr>
<td>Steam turbine system $^b$</td>
<td>5.36</td>
<td>0.7</td>
<td>10.3 MWe</td>
</tr>
</tbody>
</table>

$^a$ Wooley et al., 1999
$^b$ Hamelinck et al., 2005
$^c$ Eijsberg, 2006
Table 5—Costs of the biomethanol system components in MUS$2008.

<table>
<thead>
<tr>
<th>Component</th>
<th>Base investment costs</th>
<th>Scaling factor</th>
<th>Base scale</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pre-treatment</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conveyors</td>
<td>0.085</td>
<td>0.76</td>
<td>54.5 t_{dry base}/h</td>
</tr>
<tr>
<td>Dryer</td>
<td>0.074</td>
<td>0.76</td>
<td>184 m^3</td>
</tr>
<tr>
<td>Feeding system</td>
<td>0.44</td>
<td>1.00</td>
<td>33.5 t_{wet base}/h</td>
</tr>
<tr>
<td><strong>Gasification system</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IGT</td>
<td>38.1</td>
<td>0.7</td>
<td>68.8 t_{dry base}/h</td>
</tr>
<tr>
<td>Oxygen plant (installed)</td>
<td>47.51</td>
<td>0.85</td>
<td>41.7 t O_2/h</td>
</tr>
<tr>
<td><strong>Gas Cleaning System</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyclone</td>
<td>2.79</td>
<td>0.7</td>
<td>34.2 m^3/s</td>
</tr>
<tr>
<td>High Temperature Heat Exchanger</td>
<td>7.50</td>
<td>0.6</td>
<td>39.2 kg steam/s</td>
</tr>
<tr>
<td>Bag Filter</td>
<td>1.72</td>
<td>0.65</td>
<td>12.1 m^3/s</td>
</tr>
<tr>
<td>Scrubber</td>
<td>2.79</td>
<td>0.7</td>
<td>12.1 m^3/s</td>
</tr>
<tr>
<td><strong>Syngas Conditioning</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compressor</td>
<td>11.92</td>
<td>0.85</td>
<td>13.2 MWe</td>
</tr>
<tr>
<td>Steam Reformer</td>
<td>10.09</td>
<td>0.6</td>
<td>1390 kmol total/h</td>
</tr>
<tr>
<td>Shift Reactor (installed)</td>
<td>39.61</td>
<td>0.85</td>
<td>15.6 Mmol CO+H_2/h</td>
</tr>
<tr>
<td>CO_2 Selexol Remover (installed)</td>
<td>58.08</td>
<td>0.7</td>
<td>9909 kmol CO_2/h</td>
</tr>
<tr>
<td><strong>Methanol Production</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methanol Synthesis (Gaseous phase)</td>
<td>7.51</td>
<td>0.6</td>
<td>87.5 t MeOH/h</td>
</tr>
<tr>
<td>Refining</td>
<td>16.21</td>
<td>0.7</td>
<td>87.5 t MeOH/h</td>
</tr>
<tr>
<td><strong>Power generation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steam Turbine System</td>
<td>5.36</td>
<td>0.7</td>
<td>10.3 MWe</td>
</tr>
</tbody>
</table>

* Wooley et al., 1999  
** Eijsberg, 2006  
† Hamelinck and Faaij, 2001

Techno-economic performance

For the ethanol production plant using SSF and SSCF enzymatic hydrolysis, the enzyme costs represent 66 and 70% of the total biofuel production costs, respectively. The costs of the cane bagasse, investment, M&O (maintenance and operation) and electricity commercialisation revenues, represented 21 and 17%; 17 and 15%; 3 and 3%; –7 and -6%, respectively. The electricity generated in co-generation systems has negative revenue, which results in biofuels production cost decrease.

Out of the sensitivity analysis, when varying the enzyme costs ±55%, a sharp reduction is observed in the production cost of bioethanol down to 0.48 US$/L. Other parameter variations do not affect the production costs significantly (Figure 3).

Fig. 3—Sensitivity analysis of the bioethanol SSF enzymatic hydrolysis.
The behaviour of the production costs for the SSCF case is very similar to SSF. A reduction of 55% in the cost of the enzymes results in an ethanol production cost of 0.314 US$/L. Significant changes in the production costs are not observed for variations in the other economical parameters.

Although the bioethanol production cost through SSF technology is larger than the production cost by the SSCF method (0.48 and 0.45 US$/L of bioethanol, respectively), these costs are still are very high when compared with the costs of ethanol starting from sugarcane juice and from corn, as shown in Figure 4.

The cost of the enzymes used in this work was taken from information published in the news section of the Ministry of External Relations of Brazil related to NovoEnzymes data (0.32 US$/L bioethanol). The enzyme manufacturing companies are focused on reducing these prices by several times, which would make the process profitable (Ministry of External Relations of Brazil, 2008).

The biofuel production cost was calculated for different scenarios, as presented in Figure 5. Scenario 2 corresponds to the more optimistic one, with an enzyme cost of 0.05 US$ per litre of produced bioethanol (Novozymes, 2008; Bon, 2007). Scenario 1 is more pessimistic with a cost of 2 US$/L bioethanol (Bon, 2007). Scenario 3 was the one considered in this research.

![Fig. 4—Comparison of ethanol production costs from bioethanol starting from enzymatic hydrolysis (SSCF and SSF) and the conventional processes from sugarcane and corn.](image1)

![Fig. 5—Comparison of the costs of the bioethanol produced from enzymatic hydrolysis for different scenarios.](image2)
Different from the case of the biochemical platform, in the thermochemical one the largest percentage of the biofuel production cost corresponds to investment with 65%, followed by the fixed costs of M&O, cost of sugarcane bagasse and electricity commercialisation revenues with 22%, 18% and –4%, respectively.

Making a sensitivity analysis, varying the costs ±55%, it is observed that the production cost is strongly influenced by the investment and, consequently, for the fixed costs of M&O. The fluctuation of the bagasse costs between –55 and +55% leads to biomethanol costs of 0.23 and 0.27 US$/LMeOH, respectively, as shown in Figure 6.

![Fig. 6—Sensitivity analysis of the biomethanol production costs starting from biomass gasification.](image)

In Figure 7, the cost of production of the methanol obtained from biomass is shown compared with the production cost starting from natural gas. It is observed that the production cost of methanol obtained through the first technology is greater than the second one with 0.25 US$/L and 0.11 US$/L, respectively.

![Fig. 7—Methanol production costs when using biomass and natural gas as feedstock.](image)
Seeking the comparison of the biochemical and thermochemical routes, as is shown in Figure 8, the biofuel production cost in US$/GJ\text{HHV}. It is observed that, in spite of the total investment cost of the biomethanol plant being much higher than for the bioethanol plants, the cost of production of the bioethanol starting from the enzymatic hydrolysis is higher than the cost of production of the biomethanol This is due mainly to the high annual total costs involved in the biochemical platform.

![Figure 8](image)

Fig. 8—Total investment costs (bars, left axis) and biofuels production cost (points, right axis) for the biochemical and thermochemical platforms for obtaining second generation biofuels.

A similar behaviour is observed when the biofuel production for plant capacity of 400 MW\text{th} and the production costs are compared (Figure 9).

![Figure 9](image)

Fig. 9—Annual total production (bars, left axis) and second generation biofuels production cost (points, right axis) for the biochemical and thermochemical platforms.
Another scenario comes when the most optimistic case for the biochemical platform is considered. In this case, it is possible to reach ethanol production costs greater than biomethanol ones, that are 13.68 and 11.73 US$/GJ respectively, as shown in Figure 10.

It is also observed that, for the more optimistic scenario of the biochemical platform, the ethanol production cost becomes competitive when compared with the production costs of the sugarcane juice ethanol.

Considering the process energy efficiency (GJ product / GJ required), the biomethanol production starting from biomass presents a greater value, of 45.3%, than ethanol production through enzymatic hydrolysis types, both SSCF and SSF, that have an efficiency of 34.08 and 25.78%, respectively. It should be pointed out that energy efficiencies were calculated taking into account only the energy content of biofuel.

The estimated efficiencies in this study don't differ too much from efficiencies found in the literature. According to Hamelinck et al. (2005), for the process of ethanol production starting from enzymatic hydrolysis, the efficiency varies in the range from 30 to 40%. For the biomethanol process starting from biomass gasification, they are around 50% (Hamelinck and Faaij, 2001; Cardenas, 2006).

Discussion and conclusions

Production costs of 22.7 and 21.32 US$/GJ_{ETOH} were obtained from the economic analysis of the processes of ethanol production through SSF and SSCF enzymatic hydrolysis, respectively. These costs are not competitive when compared with the costs of the conventional processes for ethanol production starting from sugarcane juice and corn.

The high current production costs that characterise the biochemical route are strongly influenced by the costs of the enzymes (0.32US$/L_{ETOH}), that represent from 66 to 70% of the annual total costs. The implementation of the enzymes production ‘in situ’ could reduce costs, and lead to the economical feasibility of the process.
A reduction of the enzyme costs down to 0.05 US$/L$_{ETOH}$ would make the lignocellulosic ethanol production process competitive when compared with the conventional routes of ethanol production. Besides, it would lead to lower production costs than in the case of the thermochemical platform.

For the thermochemical platform, the estimated methanol production cost is 15.82 US$/GJ$_{MeOH}$, significantly less than for the biochemical platform. However, the cost of production of the methanol from biomass is higher than from natural gas (6.96 US$/GJ$_{MeOH}$).

**REFERENCES**


INDICATEURS TECHNO-ÉCONOMIQUES POUR LA PRODUCTION DE BIOCARBURANTS A PARTIR DE LA BAGASSE DE CANNE A SUCRE PAR DES PROCEDES THERMO-CHIMIQUE ET BIOCHIMIQUE

Par

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MOTS-CLÉS: Biocarburants de Deuxième Génération,
Bagasse de Anne à Sucre, Procédé Biochimique, Procédé Thermochemique.

Résumé

L'OBJECTIF PRINCIPAL de cette communication est de comparer les itinéraires biochimique et thermochemique pour la production de biocarburants de deuxième génération à l'aide des indicateurs deficiencies et d’ordre économique. Dans les deux cas, la matière première utilisée est la bagasse de canne à sucre. Les prévisions ont été effectuées pour une usine de biocarburants ayant une consommation de bagasse de canne à sucre de 1772 tonnes jour⁻¹ en matière sèche, équivalent à 400 MW d'énergie thermique. L'utilisation de sous-produits, comme la lignine dans la voie biochimique et de la bagasse de canne à sucre pour attendre l’auto suffisance en vapeur et en électricité par cogénération ont été également prise en considération. Le coût élevé de production de bioéthanol obtenu par le procédé biochimique (US $ 21.32 à 22,7/GJETOH) est fortement influencé par le coût élevé de l'enzyme. Le coût de production de biométhanol par la procédé thermochemique (15.82 $ US/GJMeOH) est principalement influencé par le coût élevé des équipements.
INDICADORES TÉCNICO-ECONÓMICOS PARA LAS VÍAS TERMOQUÍMICA Y BIQUÍMICA PARA LA PRODUCCIÓN DE BIOCOMBUSTIBLES, EMPLEANDO BAGAZO DE LA CANA DE AZÚCAR COMO MATERIA PRIMA

Por

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PALABRAS CLAVE: Biocombustibles de Segunda Generación, Bagazo de Caña de Azúcar, Vía Bioquímica, Vía Termoquímica.

Resumen

El principal objetivo de este trabajo es comparar las vías bioquímica y termoquímica en el comportamiento de la producción de biocombustibles de segunda generación, empleando indicadores económicos y de eficiencia. En ambos casos a partir de bagazo. Los cálculos se realizaron para una planta de biocombustible con un consumo de bagazo de 1772 t/día base seca, equivalente a 400 MW de energía térmica. Se consideró, así mismo, el empleo de subproductos tales como la lignina en la vía bioquímica y el bagazo para la autosuficiencia de vapor y electricidad a través de la cogeneración. El alto costo de producción del etanol obtenido por la vía bioquímica (21.32 a 22.7 US$/GJ etoh) está influido por el costo de la enzima. El costo de producción del biometanol por la vía termoquímica (15.82 US$/GJ meoh) está influido por el elevado costo del equipamiento.
THE BIOLOGICAL UTILISATION OF BAGASSE: A SOUTH AFRICAN PERSPECTIVE

By

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KEYWORDS: Bagasse, Collaborative Research, Enzymatic Ethanol, Economic Drivers.

Abstract

In the early 1980s, the Sugar Milling Research Institute was part of a national collaborative program entitled ‘The Biological Utilisation of Bagasse’. The aim was to develop and evaluate the expertise and technology required to provide biomass fermentation substrates (specifically from sugarcane bagasse) for ethanol, single cell protein and other industrial products. A number of processes were successfully developed on a pilot scale including acid hydrolysis, direct fermentation of the hydrolysate, production of single cell protein, hydrolysed fibre preparation for enzymatic hydrolysis using attritor milling and the production of very high activity cellulase. The processes were developed on a sufficiently large scale to allow for economic evaluation. Given the current interest in cellulosic fuels, the proposed use of sugarcane biomass feedstock for value-added addition and the possibility of sustaining ailing sugar industries, this paper highlights the processes that made the program successful, compares the historical and current economic and technical drives and comments on some current thinking in this field.

Introduction

In the early 1980s, the Sugar Milling Research Institute (SMRI) was part of a national collaborative research program entitled ‘The Biological Utilisation of Bagasse’.

The aim of this program was to develop and evaluate the expertise and technology required to provide biomass fermentation substrates (specifically from sugarcane bagasse) for the production of ethanol, single cell protein and other industrial products.

This paper serves to highlight the diverse socio-, economic and technological drivers of that period that impacted on the program, explain the program and the outcomes achieved, reasons for its success and finally draws parallels to current drivers.

Economic drivers

During the 1970s, the world economy was stressed by two oil crises: in 1973, when Middle Eastern oil producing nations proclaimed an oil embargo in response to the U.S. decision to re-supply the Israeli military during the Yom Kippur war; and in 1979, in the wake of the Iranian Revolution.

Crude oil prices went as high as $100 / barrel (expressed in 2009 dollars) (Figure 1). The major producers of the time were the United States, Russia, Saudi Arabia and Iran.

The South African economy was, in addition to the international crude oil crises, being challenged by the start of selected economic sanctions.

Most of the country’s crude oil was being sourced from Iran until the fall of the Shah in 1978.
In 1955, a South African company called South African Synthetic Oil Limited (SASOL) started producing petrol, liquefied petroleum gas and other chemicals from coal using the Fischer-Tropsch process at Sasolburg (Collings, 2007).

Together with Total SA and the National Iranian Oil Company, a refinery (NATREF) was established in 1967 based on Iranian crude. Because of the 1973 oil crises, a second oil-from-coal complex was established (SASOL II), coming on-line in 1980. As a consequence of the Iranian Revolution and drying up of supplies from that country, a third SASOL complex was built adjacent to the SASOL II complex, coming on stream in the mid 1980s.

The three plants supplied approximately half of the country’s liquid fuel requirements at the time. (This has declined over time as Sasol currently supplies approximately 36% of the country’s fuel requirements (Anon., 2009a)).

Technological drivers

The 1970s witnessed an upsurge in technological advances that aided scientists. Examples include the adoption of liquid chromatography as a routine analytical technique due to advances in instruments and column packing material synthesis. These advances had a direct effect on the biological sciences with advances in molecular biology, bacteriology and genetics laying the foundations for the modern forms of these disciplines.

In 1973, Stanley Cohen and Herbert Boyer pioneered the techniques to create recombinant DNA (Anon, 2009b). This technology became the beginning of the biotechnology industry. Genetech was founded in 1976 with the aim to produce materials from the emerging technology. This set the stage for the investigation and use of biotechnology in the lignocellulosic field.

The program and its outcomes

During the 1970s, the Council for Scientific and Industrial Research (CSIR) funded stand-alone research at a number of different centres into the utilisation of lignocelluloses. In 1979, this research was consolidated into a goal-orientated, cooperative program to focus the effort on a single
lignocellulosic material, to produce a single product and a single conversion process. The goal of the program was the development of a technically and commercially viable process to convert bagasse to ethanol (Paterson-Jones, 1989). Liquid fuel production was perceived as important at the time due to the drivers already mentioned.

Although several lignocellulosic resources were potentially available, bagasse was chosen because it was already being collected at a central location (the mill), it could be produced in excess of the mill’s energy requirements and the mill could provide an established industrial infrastructure for a bagasse processing plant. Ethanol was chosen as the preferred end product because it had potential for use as both a liquid fuel and as a chemical feedstock. An enzymatic saccharification process for cellulose hydrolysis cellulose was chosen because it held the promise of providing a high yield under mild conditions. It was also viewed that the enzyme process held the potential for improvement through research. The sponsors accepted that the program was a high risk venture but that it held potential benefits to South Africa. These included the development of a process which could be applied to other lignocellulosic wastes (with minor modifications) and produce a range of products including ethanol.

Eleven institutions throughout South Africa collaborated in the program. A total of fourteen research groups with a range of expertise in enzymology, microbiology, genetics and engineering were involved over the nine year period (Anon, 1989). The program was managed with a coordinator at both the scientific and administrative level and made extensive use of a steering committee. SMRI played a pivotal role as a contact point between the researchers in the program and the sugar industry. The Institute also hosted and was responsible for running the process development unit that ran for more than two years. The results from the development unit were used for subsequent economic modelling.

The program achieved successful outcomes in both the technical and human capital development arenas. Technically these included:

- The development of an acid-based extraction and hydrolysis of hemicellulose to xylose and other monomeric sugars using dilute acid.
- Direct fermentation to alcohol of the sugars in the hemicellulose hydrolysate.
- Production of single cell protein from the hemicellulose hydrolysate.
- Treatment of acid-extracted bagasse by attritor milling.
- Simultaneous enzymatic hydrolysis of the cellulose in acid-extracted, attritor milled bagasse and its fermentation to ethanol.
- Production of very high activity cellulase enzyme (57 IU/mL).

Human capital development within the program was evidenced by the awarding of 13 MScs, 5 PhDs, 47 papers in international peer reviewed journals, 33 conference papers and local expertise developed in fermentation research and technology and associated fields.

During the course of the program (1979 to 1987), a number of significant changes occurred within the drivers which had been present at the beginning of the program. The most significant globally was the decline in crude oil prices back to levels approaching the early 1970s (Figure 1).

The second significant change within the South African context was the coming on-line of the SASOL II and III plants (Collings, 2007). A by-product of the synthesis processes being used at that time was ethanol, which directly affected the potential development of a fuel alcohol industry. Throughout the duration of the program, the economic potential of not only ethanol but other products was investigated as the economic background changed. Potential products investigated included acetone, n-butanol, acetic acid, butane-2,3-diol, xylose, furfural, butadiene, sugar alcohols (mannitol, xylitol, etc), organic acids (citric, tartaric, lactic, etc) and amino acids.
Based on the processes developed and optimised using the process development plant, an economic evaluation showed that (Purchase, 1989):

- the production of ethanol from enzymic hydrolysed bagasse was not economically promising due to the high cost of enzyme;
- the production of single cell protein from hemicellulose hydrolysate was possible;
- the production of ethanol from hemicellulose hydrolysate was marginal.

**Parallels to the present and future potential**

On an international scale, some of the current economic drivers have parallels to those that were present in the late 1970s in South Africa and have to be considered when reviewing participation in renewable cellulosic feedstock research and developing related economic models. These include the fluctuating crude oil prices (such as the highs of 2008 which have subsequently declined in a similar fashion to the early 1980s (Figure 1)), the increasing supply of internationally traded fuel alcohol (particularly from Brazil which supplies more than 50% of global alcohol), the cost of finance (Tuxen, 2009) and the next step in the evolution of analytical instrumentation.

The sensitivity and types of instruments currently available provide the researcher with the ability to understand reactions and interactions at a molecular level which again promises to build a platform to make rapid progress in the enzyme field. However, although much progress has been reportedly achieved in enzyme efficiencies and reducing costs of production, enzyme costs are still considered to be inhibiting factors to the adoption of the technology (Tuxen, 2009).

In addition, a number of new economic drivers that were not present in the 1980s now have to be considered when venturing into renewable biomass research. These include global warming, land use change policies (Anon, 2009c), government policies relating to carbon credits and carbon tax (Winkler and Marquard, 2009), the United States Renewable Fuel Standard Program (Anon, 2009d) and similar programs which may include subsidies (Askew, 2003; Tuxen, 2009). The inclusion of these drivers in economic models for renewable energy makes long-term forecasting more difficult than 25 years ago.

From a sugar industry perspective, the use of sugarcane as a biomass source has many advantages including the plant being one of the most efficient utilisers of the sun’s energy and collection of the biomass at central locations. These advantages often encourage a perception among researchers outside the industry to view bagasse as an almost limitless resource freely available for enzymic conversion to fuel alcohol. Sugar mills are generally not energy efficient but rather energy sufficient: the energy produced from bagasse matches the desired configuration and operation of the plant and any other ancillary factories.

Large quantities of the raw material are therefore not necessarily available. Purchase and Wienese (2004) reviewed co-generation using bagasse and fuel alcohol from molasses, sugar and biomass hydrolysis. The authors estimated that, in the South African context, about one third of all bagasse is available for cellulosic ethanol production. This would contribute less than 1% of the current annual fuel requirements of the country (Anon, 2009a). It was concluded that the use of bagasse for co-generation is a better option than ethanol from cellulosic hydrolysis.

**Conclusion**

The biological utilisation of bagasse program was successful in both its technological and socio-economic outputs even though it did not create a new industry. There are lessons that can be learnt for any consortium planning an integrated approach to research.

The success was founded in well defined, achievable goals and appointing one leader responsible for co-ordination and overseeing the whole project. The outputs of the research were continually tested against the economic drivers within the context of the overall program goals.
Although there are many parallels between the current divers and those present in the 1980s, additional policies now make biomass derived renewable energy economically attractive. However, the widespread adoption of cellulosic enzymatically derived biofuels from sugarcane bagasse still has many barriers to overcome when compared to adoption of co-generation.

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L'UTILISATION BIOLOGIQUE DE LA BAGASSE: UNE APPROCHE SUD AFRICAINE

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MOTS-CLÉS: Bagasse de Canne à Sucre, Recherche Collaborative, Éthanol Enzymatique, Motivation Économique.

Résumé

AU DÉBUT des années 1980, le Sugar Milling Research Institute faisait partie d'un programme de collaboration national intitulé "L'utilisation Biologique de la Bagasse". L'objectif était de développer et d'évaluer l'expertise et la technologie nécessaires pour fournir des substrats de fermentation de biomasse (plus précisément à partir de la bagasse de cannes à sucre) pour la production d'éthanol, la protéine unicellulaire et d'autres produits industriels. Un certain nombre de procédés ont été développés avec succès à l'échelle pilote, y compris l'hydrolyse en milieu acide, la fermentation directe de l'hydrolysat, la production de protéines unicellulaires, la préparation de la fibre par l'hydrolyse enzymatique à l'aide d'un défibreur et de la production de cellulase à très forte activité. Les procédés ont été développés sur une échelle suffisamment grande pour permettre une évaluation économique. Compte tenu de l'intérêt actuel pour des combustibles à base de cellulose, l'utilisation proposée de la biomasse de la canne à sucre pour des produits à forte valeur ajoutée et la possibilité de venir en aide à des industries sucrières en difficulté, cette communication met en exergue les procédés qui ont fait le succès du programme, fait la comparaison entre les aspects historiques et courants des motivations économiques et techniques et offre des commentaires sur la reflexion actuelle dans ce domaine.

LA UTILIZACIÓN BIOLÓGICA DEL BAGAZO: UNA PERSPECTIVA SURAFRICANA

Por

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PALABRAS CLAVE: Bagazo, Investigaciones Colaborativas, Etanol Enzimático, Conductores Económicos.

Resumen

A INICIOS de los 1980s, el Sugar Milling Research Institute era parte de un programa nacional colaborativo denominado ‘La utilización biológica del Bagazo’. El objetivo era desarrollar y evaluar el nivel de especialización y la tecnología requerida para proveer un sustrato fermentable basado en biomasa (específicamente a partir de bagazo de caña de azúcar) para etanol, proteína unicelular y otros productos industriales. Se desarrollaron exitosamente un grupo de procesos a escala piloto, incluyendo hidrólisis ácida, fermentación directa de los hidrolizados, producción de proteína unicelular, preparados de fibras hidrolizadas para la hidrólisis enzimática empleando molinos de atrición y la producción de una celulasa muy activa...los procesos se desarrollaron a una escala suficientemente grande que permitía su evaluación económica. En razón del actual interés en combustibles celulósicos, la propuesta de empleo de alimentos de la biomasa de la caña de azúcar para generar valor agregado y la posibilidad de una industria azucarera sostenible, este trabajo destaca los procesos que hicieron exitoso el programa, compara los promotores económicos históricos y actuales, así como los tecnológicos y comenta sobre algunas consideraciones actuales en este campo.
ISOLATING AND SELECTING MICROORGANISMS TO OBTAIN CELLULOSE SUSTAINABLY

By

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KEYWORDS: Lignolytic Fungi and Bacteria, Biotechnological Production of Cellulose, Sugarcane Bagasse.

Abstract

Actual chemical processes able to obtain cellulose from sugarcane bagasse are very toxic and pollutant. The objective of this work was to find native microorganisms able to delignify bagasse helping to raise its cellulose content, without affecting actual fibres, in order to obtain higher quality paper. Advantages of biological delignification compared to chemical methods are: softer reaction conditions, higher product yields and less energy consumption. Another advantage is the improvement in the paper’s mechanical properties such as tensile strength. For isolation and identification of the microorganisms, such as bacteria and fungi, sugarcane bagasse was used as the only substrate, which was obtained from a Mexican sugar mill. The plate dilution and enrichment culture techniques were applied. Six native strains of fungi and four of bacteria have been isolated, some of them with potential capacity to degrade the lignin which is due to lignolytic extracellular enzyme production, yielding laccases and peroxidases. Obtained results indicate that biotechnological lignin degradation is possible using native microorganisms from sugarcane bagasse thus eliminating chemical processes. The biological delignification of the sugarcane bagasse for obtaining cellulose could be considered as a sustainable process not only because of the recycling of this by-product but also because it is environmentally friendly.

Introduction

Sugarcane bagasse is a by-product of the sugar industry consisting principally of cellulose, hemicellulose and lignin. It is the fibrous residue of sugarcane after the juice has been extracted. In Mexico, more than 95% of the bagasse is used by the sugar factories as fuel for the boilers. In recent years, alternative and more profitable uses of bagasse are being investigated.

Bagasse has been used for the production of enzymes, amino acids, drugs, ethanol, and single-cell protein as animal feed after treating it with a large variety of microorganisms including bacteria, yeasts, and fungi, among which Basidiomycetes are preferred (Eriksson, 1990). However, such bio-processes require only small quantities of substrate and would not utilise all available bagasse (Xin et al., 2002).

Due to increasing restraints on forest harvesting, the use of agro-based residues for pulp and paper production has been steadily increasing in recent years (Bustamante et al., 1999). The sugarcane bagasse is a biomass that can be used as raw material for pulp and paper production, which in turn yields new paper, dissolvable pulp and cellulose-based filter paper for soft drinks and other liquids (Valdes, 2007).
Lignin is the most abundant renewable source of aromatic polymers in nature, and its degradation is therefore of general significance for the global carbon cycle. It is chemically recalcitrant to breakdown by most organisms because of the complex, heterogeneous structure. The most efficient and most investigated lignin-degrading microorganisms are the wood-decaying Basidiomycetes causing white-rot. They contain the extracellular oxidative enzymes laccases and peroxidases (Gao et al., 1997).

The major groups of lignolytic enzymes include lignin peroxidases, manganese peroxidases, versatile peroxidases, and laccases. The peroxidases are heme-containing enzymes with catalytic cycles that involve the activation by H₂O₂ and substrate reduction of compound I and compound II intermediates. Lignin peroxidases have the unique ability to catalyse oxidative cleavage of C–C bonds and ether (C–O–C) bonds in non-phenolic aromatic substrates of high redox potential. Manganese peroxidases oxidise Mn(II) to Mn(III), which facilitates the degradation of phenolic compounds or, in turn, oxidises a second mediator for the breakdown of non-phenolic compounds. Versatile peroxidases are hybrids of lignin peroxidase and manganese peroxidase with a bifunctional characteristic. Laccases are multi-copper-containing proteins that catalyse the oxidation of phenolic substrates with concomitant reduction of molecular oxygen to water (Wong, 2009).

Breccia et al. (1997) screened several white-rot fungi to degrade long-fibre bagasse aiming at bio-pulping and found that about 16% of the lignin was removed. Biological pulping has the potential to reduce energy costs and environmental impact compared to traditional pulping operations (Breen and Singleton, 1999).

The objective of this work was isolating and identifying the strains of native microorganisms which assist in delignifying bagasse and as a result raise its cellulose content. The enrichment culturing technique was used. Thus, cellulose would become a by-product of the cane sugar industry. The present study describes a simple system for isolating and screening of microorganisms, either fungi or bacteria, which have lignolytic activities.

Materials and methods

Sample source

The sugarcane bagasse samples were provided by Ingenio San José de Abajo, from Veracruz, México.

Culture media

- Saline medium for enrichment cultures. Composition in g/L: KNO₃ 1.0; FeCl₃ 0.02; MgSO₄ 0.2; NaCl 0.1; CaCl₂ 0.1; K₂HPO₄ 1.0 and yeast extract 0.05. The pH of the medium was adjusted to 6.3 with a 0.1 N HCl solution.
- Saline Agar. This medium contains the same components as the saline medium, but is complemented with 1.5% (w/v) bacteriological agar. The pH of the medium was also adjusted to 6.3 with a 0.1 N HCl solution.
- Malt Extract Agar. Malt extract Agar (Difco). Sabouraud Dextrose Agar (BD Bioxon), and Nutritive Agar (BD Bioxon).

Microorganisms isolation

The isolation of the microorganisms, bacteria as well as fungi, was done from sugarcane bagasse applying enrichment culturing.

Sugarcane bagasse was washed with water at 60°C in order to remove the sugar. It was used as the only substrate. Then, 1.0 g of this bagasse was added into a 250 mL Erlenmeyer flask which contained 125.0 mL of the saline medium. It was cultured by shaking for three days at 25°C and 180 rpm. After being incubated for three days, 12.0 mL of the supernatant was transferred to an Erlenmeyer flask of 250 mL containing 125 mL of fresh medium, which was cultured at the same above described conditions. This process was repeated three times.
Isolation and identification of microorganisms

After three transfers, 0.1 mL of sample from the recuperated medium was spread on saline agar plates and incubated at 26°C for 24 hours. For isolation, the obtained colonies were inoculated on to nutritive agar plates if they were bacteria or on malt extract agar and Sabouraud dextrose agar if they were fungi. The plates were incubated for another 24 h at 35°C and for 72 h at 26°C, respectively.

The fungi were primarily identified based on their characteristics of colonial morphology and structure. For the structure identification, a micro-culture from each isolated colony was prepared, which was incubated at 26°C until sporulation. Final fungi identification was done after staining with lactophenol-cotton blue and observation under the microscope. Photos were taken.

Bacteria could be identified based on their colonial morphology and biological characteristics, and physiological and biochemical tests including Gram reaction (Buchanan and Gibbons, 1974).

Results

The results show ten strains of microorganisms, which were obtained by the enrichment culture technique using sugarcane bagasse as the only source of carbon and energy. Of the ten strains isolated, six were fungi, which are named F-1 through F-6; the others were bacteria and are named B-1 through B-4. Figure 1 shows the macroscopic and microscopic characteristics of isolated fungi and their corresponding identification. The morphology and Gram reaction of the isolated bacteria are shown in Figure 2. Table 1 shows the physiological and biochemical characteristics of strains of isolated bacteria.

<table>
<thead>
<tr>
<th>Strain</th>
<th>Obverse</th>
<th>Reverse</th>
<th>Micrography</th>
</tr>
</thead>
<tbody>
<tr>
<td>F-1 Penicillium sp.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F-2 Penicillium sp.</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>F-3 Fusarium sp.</td>
<td></td>
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<tr>
<td>F-4 Cladosporium sp.</td>
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<tr>
<td>F-5 Mucor sp.</td>
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<td></td>
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<tr>
<td>F-6 Geotrichum sp.</td>
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</tbody>
</table>

Fig. 1—Macroscopic and microscopic characterisation for fungi isolated and identified.
Table 1—Physiological and biochemical characteristics of strains of bacteria.

<table>
<thead>
<tr>
<th>Strain</th>
<th>B-1</th>
<th>B-2</th>
<th>B-3</th>
<th>B-4</th>
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</thead>
<tbody>
<tr>
<td>Shape</td>
<td>Rod</td>
<td>Rod</td>
<td>Rod</td>
<td>Rod</td>
</tr>
<tr>
<td>Gram reaction</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Mobility or not</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Methyl red</td>
<td>+</td>
<td>–</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Voges Proskauer</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Catalase</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Oxidase</td>
<td>–</td>
<td>+</td>
<td>–</td>
<td>+</td>
</tr>
<tr>
<td>Starch hydrolysis</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Glucose fermentation</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Citrate utilisation</td>
<td>+</td>
<td>+</td>
<td>+</td>
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</tr>
</tbody>
</table>

Fig. 2—Micrographics that show the morphology and Gram reaction of the bacteria isolated, where B-1, B-3 and B-4 have been identified as *Bacillus subtilis* and B-2 as *Bacillus sp*.

Conclusions

There are reports in the literature on several identified lignolytic fungi and bacteria suitable for biotechnological processes on bagasse permitting diversification of the sugar industry (Meza *et al*., 2006; Ramos *et al*., 2001; Viñals Verde *et al*., 2006; Xin *et al*., 2002).

In this study, six different native strains of fungi were isolated and identified: *Penicillium sp.* (two strains), *Fusarium sp.*, *Cladosporium sp.*, *Mucor sp.* and *Geotrichum sp.*; also four bacteria, all of the gender *Bacillus*. The production of lignolytic enzymes by these microorganisms will be tested later with liquid cultures.

It is also intended continuing this work to isolate fungi of the *Basidiomycetes* group, which are reported as having higher lignolytic capacity.

Acknowledgements

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L’ISOLEMENT ET LA SÉLECTION DES MICRO-ORGANISMES POUR LA PRODUCTION DURABLE DE CELLULOSE

Par

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MOTS-CLÉS: Champignons et Bactéries Lignolytiques, Production Biotechnologique de Cellulose, Bagasses de la Canne à Sucre, Canne à Sucre.

Résumé

Les processus chimiques courants, capables d'obtenir la cellulose à partir de la bagasse de canne à sucre sont très toxiques et polluants. L'objectif de ce travail était de trouver des micro-organismes natifs capables de delignify bagasse contribuant à augmenter son contenu de cellulose, sans affecter les fibres réelles, afin d'obtenir des papiers de qualité supérieure. Les avantages de la délignification biologique par rapport aux méthodes chimiques sont : conditions de réaction plus douces, hausse des rendements de produit et moins de consommation d'énergie. Un avantage supplémentaire est l'amélioration des propriétés mécaniques du papier telle que la traction. Pour l'isolement et identification des micro-organismes, comme les bactéries et champignons, seule la bagasse de canne à sucre a été utilisée comme unique substrat, obtenu à partir d'une sucrerie mexicaine. Les techniques de culture de dilution et d'enrichissement de plaque ont été appliquées. Six souches de champignons et quatre de bactéries à l’état naturel ont été isolées, certaines d'entre elles avec une capacité potentielle de dégrader la lignine de la cellulose qui est due à la production d'enzymes extracellulaires lignolytiques, produisant des laccases et peroxidases. Les résultats obtenus indiquent que la dégradation de la lignine par biotechnologie est possible à l'aide de micro-organismes trouvés de la bagasse de canne à sucre éliminant ainsi les processus chimiques. La délignification biologique de la bagasse de canne à sucre pour l'obtention de cellulose pourrait être considérée comme un processus durable non seulement en raison du recyclage de ce sous-produit mais aussi parce qu'il est plus respectueux de l'environnement.
AISLAR Y SELECCIONAR MICROORGANISMOS PARA OBTENER CELULOSA SOSTENIBLE

Por

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PALABRAS CLAVE: Hongos y Bacterias Lignolíticas,
Producción Biotecnológica de Celulosa,
Bagazo de la Caña de Azúcar.

Resumen

Los procesos existentes capaces de obtener celulosa del bagazo de la caña de azúcar son muy tóxicos y contaminantes. El objetivo de este trabajo fue encontrar nativos microorganismos capaces de delignify bagazo ayudando a elevar su contenido de celulosa, sin que ello afecte a fibras reales, con el fin de obtener mayor papel de calidad. Las ventajas de la delignificación biológica en comparación con los métodos químicos son condiciones de reacción más suaves, mayores rendimientos de productos y menores consumos de energía. Otra ventaja es el mejoramiento de las propiedades mecánicas del papel, tales como la fuerza tensil. Para el aislamiento y el identificación de los microorganismos, tales como bacterias y hongos se empleó el bagazo de caña como único sustrato, el que se obtuvo de un Central mexicano. Se emplearon las técnicas de dilución en placas y de cultivos enriquecidos. Se aislaron seis (6) razas nativas de hongos y cuatro (4) de bacterias, algunas de ellas con capacidad de degradar la lignina a celulosa debido a la producción de una enzima lignolítica extracelular, rindiendo laca y peroxidasas; los resultados obtenidos indican que la degradación biotecnológica de la lignina es posible empleando microorganismos nativos del bagazo de la caña y así eliminar los procesos químicos. La delignificación biológica del bagazo de la caña de azúcar para obtener celulosa puede considerarse un proceso sostenible, no sólo por el reciclado de este coproducto, sino también porque es amigable con el medio ambiente.
A SOFTWARE FOR SIMULATION OF FERMENTATION PROCESSES

By

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KEYWORDS: Fermentation Processes, Mathematical Modelling,
Ethanol Production, Software Simulation.

Abstract

Fermentation is a key process stage in ethanol production and has a high incidence in the overall process efficiency in distillery. For improving this efficiency, a rigorous analysis for defining the best choice in operation variables is needed. Simulation of the process is a recognised way for doing such an analysis. In this paper, the software tool FERMENTA® for simulation of fermentation processes is presented. This software tool allows simulation of continuous and discontinuous modes of fermentation. In the continuous mode of operation, several stages can be considered. In the batch mode, alternatives for feeding (batch, fed batch with different politics) can be analysed. The mathematical model includes non-stationary balances for biomass, substrate, ethanol, oxygen, energy. The kinetic expression can be selected by the user among more than 30 possibilities, taking or not into account inhibition factors in the process. Parameters in this equation can be estimated from experimental data. The result is a useful software tool that can be used for analysis of fermentation processes in industry and also for academic purposes. In this paper, the software is described and some case studies used for showing its possibilities.

Introduction

The technology of ethanol production by anaerobic fermentation of sugarcane molasses is well known. This process, used initially in the production of alcoholic drinks, reached high generalisation grade during the Second World War with the purpose of having an alternative source of fuel. Nowadays, ethanol with different purity grades is still produced from molasses and sugar juices. Their uses go from the pharmaceutical and cosmetics industry to the production of alcohol used as fuels by vehicles.

Keeping in mind the multiple uses of ethanol, there is an intensified interest in the study of all steps involved in ethanol production in order to reduce costs. Mathematical modelling reduces research costs by eliminating part of the experimental work, because it allows the study of process parameter interactions through simulation. Besides, it provides understanding of the process, which is helpful for operational policy definitions and can be applied for later optimisation and control.

In this paper, the mathematical model of alcohol fermentation process and FERMENTA 4.0 software, designed for simulating this process, is presented. This software could be useful in other fermentative processes because it reduces costs by eliminating part of the experimental work and allows the study of process parameter interactions through simulation.

Finally, we present a case study where the influence of some operational conditions on the yield and productivity of fermentation processes was assessed. We compare the simulation results with typical industrial data.
Process description

The conversion of sugar to ethanol is an anaerobic biological reaction by *Saccharomyces cerevisiae* yeast cells. This yeast is used commercially and classified as heterotrophics, the necessities of coal and energy are satisfied by monosaccharides (simple sugars) like glucose. Disaccharides like sucrose can also be used after the hydrolysis of the yeast in fructose and glucose (inverted sugar).

Raw materials used for ethanol production include sugary ones: juices of different fruits, beet juices, juices of cane sugar, intermediate streams of the process like molasses, etc. Sugarcane is a raw material of easy transformation and the agronomic aspects of cultivation do not present limitations, and has been cultivated for centuries. For this reason, it is the most economical raw material.

Ethanol production is divided into two phases: respiration (yeast propagation under aerobic conditions) and ethanol fermentation under anaerobic conditions. You can calculate the theoretical yield of glucose conversion to ethanol in the fermentation stage using the Gay Lussac equation, including an estimate of the heat evolved ($Q$) during the reaction.

**Respiration**

**Aerobic conditions**

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

**Anaerobic conditions**

Glucose $\rightarrow$ Carbon Dioxide + Ethanol

$$C_6H_{12}O_6 \rightarrow 2CO_2 + 2C_2H_5OH + Q$$

$$100 \text{ g} \quad \rightarrow \quad 49 \text{ g} \quad + \quad 51 \text{ g} \quad - \quad 23.7\text{Kcal}$$

Beginning with equation (2), the theoretical yields of ethanol and $CO_2$ can be calculated.

$$y_{\text{ethanol}} = 0.51 \quad \text{g ethanol/ g glucose}$$

$$y_{\text{CO}_2} = 0.49 \quad \text{g CO}_2 / \text{g glucose}$$

The real yields, however, are smaller because part of the glucose is used in the biomass generation and maintenance energy.

There are different operating fermentation modes. The first one is the batch mode where the fermenter is inoculated and fed with substrate until its working volume is reached and the process is carried out until the biotechnological conversion of sugars to ethanol finishes. Second one is the fed-batch mode with any number of feeding streams and the last is continuous fermentation, with continuous feed of fresh medium and continuous extraction of fermented medium; the fermentation can last stably for weeks and months.

**Mathematical modelling**

Mathematical models have been used to predict the influence of operating parameters on cell concentration, substrate utilisation rate and ethanol production rate (Sabadí *et al*., 1990, Rosso *et al*., 1995, Corsano *et al*., 2004, Rivera *et al*., 2006 and Ribas *et al*., 2006). These models may lead to the development of better strategies for the optimisation of the fermentation process to ensure its economic viability.

**Microbial growth**

The growth of microorganisms can be best imagined as the increase of cell material expressed in terms of mass (or cell numbers). It is the result of a highly coordinated series of
enzymatically catalysed biological steps. Optimal expression of growth kinetics depends on optimal maintenance of the transport of the necessary nutrients in the medium to cell surface, rate of mass transfer from the medium into the cells, and environmental parameters (such as temperature and pH).

In technical literature, different models describing the growth kinetics of cells are reported. The Monod (1942) model, based on Michaelis-Menten kinetics, describes the relationship between the specific growth rate ($\mu$) and the substrate concentration limit ($S$).

$$
\mu = \mu_{\text{max}} \frac{s}{k_s + s}
$$

where:
- $\mu$: specific cell growth rate ($h^{-1}$)
- $\mu_{\text{max}}$: maximum specific cell growth rate ($h^{-1}$)
- $k_s$: saturation parameter ($g/L$). Maximum substrate concentration that can use the cells for their growth. It is defined as the substrate concentration at half the maximum specific cell growth rate.
- $S$: Substrate concentration ($g/L$)

A high substrate concentration inhibits cell growth due to the effect of osmotic pressure. The model of Andrews (1968) takes this effect into consideration.

$$
\mu = \mu_{\text{max}} \frac{s}{k_s + s + \frac{s^2}{k_{is}}}
$$

$k_{is} > \left( \frac{s^2}{2k_s} \right)$: substrate inhibition parameter ($g/L$)

Microorganisms have a certain tolerance to the concentration of alcohol in the growth medium. Increasing alcohol concentration will gradually retard microbial growth and may finally completely inhibit it. This phenomenon is included in the Levenspiel (1980) model.

$$
\mu = \mu_{\text{max}} \frac{s}{k_s + s} \left( 1 - \frac{P}{P_{\text{max}}} \right)^n
$$

Parameter value $n \in [0.3; 2.0]$

Maiorella (1984) developed a model that describes the specific production rate of ethanol and biomass considering the yeast *Saccharomyces cerevisiae*, very often used in ethanol production.

$$
\mu_p = \left[ \mu_{p_{\text{max}}} \frac{s}{k_s + s} \right] \left[ 1 - \frac{P}{P_{\text{max}}} \right]^n
$$

where:
- $\mu_p$: Specific ethanol production rate. ($g$ ethanol/ g cell h)
- $\mu_{p_{\text{max}}}$: Maximum specific ethanol production rate. ($g$ ethanol/ g cell h)
- $K_s$: Saturation parameter. ($g/L$)
- $P_{\text{max}}$: Ethanol inhibition term. ($g/L$)

The specific cell growth rate can be calculated as:

$$
\mu = E \cdot \mu_p
$$
where:

\( E \): Efficiency in the use of sugar for the cells production. (g. cell / g sugar).

Wijtzes et al. (1993) and Ratkowsky et al. (1982) develop a model with environmental parameters such as temperature \( (T) \) and \( (pH) \).

\[
\mu_{\text{max}} = \mu_{\text{opt}} * f(pH) * g(T)
\]

\( \mu_{\text{opt}} \): Value of \( \mu_{\text{max}} \) under optimal conditions \( (pH_{\text{opt}}, T_{\text{opt}}) \).

In software FERMENTA 4.0, more than 30 kinetics growth models are implemented among which are the previous ones. These models are classified in four categories:

- Models without substrate inhibition.
- Models with substrate inhibition.
- Models with ethanol inhibition.
- Models with mixed inhibition.

A fermentation system, in a general way, can be represented schematically as Figure 1. Starting from here, it is possible to write the mass balance and determine how cells, substrate and ethanol concentrations change over time.

![Fig. 1— Schematic representation of ethanol fermentation system.](image)

Cell concentration \( (g / L) \)

\( S \): Substrate concentration \( (g / L) \)

\( P \): Ethanol Concentration \( (g / L) \)

\( V \): Fermentation Volume \( (L) \)

\( F \): Flow rate \( (L / h) \)

Indices: \( e \): input. \( s \): output

**Total balance**

The mass balance equation depends on operation mode. In batch fermentation, there are no inlet and outlet flows in the fermenter and the volume remains constant. In the case of a semi-continuous fermentation, an inlet flow exists to the fermenter that can be operated in different ways.

- Feeding flow for stages: The fermenter is partially fed until sugar is exhausted. It is fed again and so forth until the vessel is filled.
• Constant feeding flow.

\[ \frac{dV}{dt} = F \]  \hspace{2cm} (10) 

• Incremental feeding.

\[ \frac{dV}{dt} = F_0e^{kt} \hspace{0.5cm} k > 0 \]  \hspace{2cm} (11) 

\[ \frac{dV}{dt} = F_0e^{kt} \hspace{0.5cm} k < 0 \]  \hspace{2cm} (12)

Lastly, in continuous fermentation, there are inlet and outlet flows.

\[ \frac{dV}{dt} = F_e - F_s \]  \hspace{2cm} (13)

**Cell mass**

Keeping in mind the same considerations mentioned, a cell mass balance can be written as follows:

\[ \frac{d(xV)}{dt} = F_e x_e - F_s x_s + V(u-k_d)x \]  \hspace{2cm} (14)

\[ \mu : \text{ Specific growth rate (1/h)} \]

\[ k_d : \text{ Specific death rate (1/h)} \]

**Substrate**

A substrate mass balance can be written as follows:

\[ \frac{d(sV)}{dt} = F_e s_e - F_s s_s - V \left[ \frac{\mu x}{Y_{x/s}} + \frac{r_p}{Y_{p/s}} + mx \right] \]  \hspace{2cm} (15)

where:

\[ Y_{x/s} : \text{ Growth yield coefficient (g cells / g substrate).} \]

\[ Y_{p/s} : \text{ Product yield coefficient (g product formed / g substrate).} \]

\[ m : \text{ Maintenance coefficient (g substrate/g cells per h).} \]

\[ r_p = \frac{dp}{dt} \text{ Product formation rate.} \]

**Product formation**

The product may be obtained from the beginning of process fermentation, together with cell growth. It can also begin to be formed during the stationary phase or begin in the growth stage and
continue in the stationary phase. In dependence of this, the kinetics of product formation is defined like:

- Product associated with growth
  \[ r_p = Y_{p/x} \mu x = \alpha \mu x \]  
  \((16)\)
  
  \(Y_{p/x} = \alpha\): Product yield coefficient (g product formed / g cells)

- Product not associated with growth
  \[ r_p = \beta x \]  
  \((17)\)

- Product partially associated with growth
  \[ r_p = \alpha \mu x + \beta x \]  
  \((18)\)

\[
\frac{d(pV)}{dt} = F_e p_e - F_s p_s + V(r_p - k_{dp} p) 
\]  
\((19)\)

\(k_{dp}\): Specific product degraded rate \((1/h)\)

**Energy balance**

An energy balance for the fermentation process can be written as follows:

\[
\frac{dQ}{dt} = Q^E - Q^S + Q_g - Q_{transf}
\]  
\((20)\)

where:

- \(Q\): Heat accumulation rate. \((\text{Kcal/h})\)
- \(Q^E\): Total heat accumulated by the inlet flow until time \(t\). \((\text{Kcal})\)
- \(Q^S\): Total heat in outlet flow until time \(t\). \((\text{Kcal})\)
- \(Q_g\): Total heat evolved by the process during the reaction. \((\text{Kcal})\)
- \(Q_{transf}\): Heat transfer by the wall. \((\text{Kcal})\)

The set of coupled relationship equations 15, 16, 20 and 21, describing the fermentation kinetics, together with equations of microbial growth, was solved numerically by employing Runge Kutta method of five order with variable step (Dormand et al., 1980). This algorithm was included in FERMENTA 4.0 software.

**Software FERMENTA 4.0**

The software FERMENTA 4.0 has been designed and implemented to be used on Microsoft Windows platforms. It has a friendly user interface and a great variety of graphical reports. The main menu of the system is shown in Figure 2, representing the fermentation process according to the configuration analysed by the end user.

The system is configurable to simulate different types of fermentation (batch, fed-batch, continuous with tanks connected in series and recycling cells with one or two stages).

For simulating the process, it is necessary to input data related to the initial conditions and several parameters of yields previously adjusted if necessary to match given fermentation results.
In Figure 2, a simulation of an alcohol fermentation is shown, operated in batch mode with a fermenter capacity of 150 m³ and biomass recycle. The initial conditions of this fermentation are typical of most industrial alcohol fermentation.

- Initial substrate concentration 150 g/L
- Initial ethanol concentration 2.32 g/L
- Initial biomass concentration 1.43 g/L

The software also allows simulating the biomass recycle by the Mellé-Boinot batch process. To do this, it is necessary to give the information about the centrifuges used, number of nozzles and the efficiency (Figure 3).
The fundamental characteristics of most used centrifuges in the ethanol industry are in a database. The calculations are carried out to obtain yeast with 92% dry matter, considering the drying efficiency in the balance.

Another important step before the simulation is to select the kinetics growth equation (Figure 4). You can see the equation of the selected growth model.

In Figure 5, you can appreciate the kinetic behaviour of the fermentation. The results predict a fermentation time of 22 hours; in industrial alcohol fermentation, this parameter is estimated to be from 20 hours to 25 hours as mean. The concentration of substrate decreased from 150 g/L to less than 3 g/L. This value is very close to the final condition of many industrial alcohol fermentations. On the other hand, the ethanol concentration increased from 2.32 g/L to 62.5 g/L, which represents an ethanol content of wine equal to 8.06° GL. This parameter varies between 8°GL and 8.5° GL in real processes. The ethanol yields were 84.06% of the theoretical values and present a good productivity of 3.34 L/m³h.
The results of the yeast recovery scheme (Figure 6) indicate that a quantity of 4105.6 kg of yeast is produced by fermentation, recovering as product around 81%. The total power consumption of centrifuges was 8.7 HP.

![Batch fermentation results, table.](image)

**Fig. 6—Batch fermentation results, table.**

**Sensitivity analysis.**

With the help of FERMENTA 4.0 software, we decided to carry out an experimental factorial design with two controllable factors, the initial concentration of substrate ($S_0$) at three levels and the fermentation temperature ($T$) at two levels. The results are given in Table 1.

**Table 1—Sensitivity analysis results.**

<table>
<thead>
<tr>
<th>Input value for model</th>
<th>Output values of model</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_0$ (g/L)</td>
<td>$T$ (°C)</td>
</tr>
<tr>
<td>----------------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>150</td>
<td>32</td>
</tr>
<tr>
<td>130</td>
<td>32</td>
</tr>
<tr>
<td>110</td>
<td>32</td>
</tr>
<tr>
<td>150</td>
<td>35</td>
</tr>
<tr>
<td>130</td>
<td>35</td>
</tr>
<tr>
<td>110</td>
<td>35</td>
</tr>
</tbody>
</table>

The sensitivity analysis shows the effect of the initial concentration of substrate on the productivity of the fermentation. When the initial substrate concentration decreased from 150 g/L to 110 g/L, the process productivity (Prod.), the ethanol content of wine (Ethanol content) and the necessary area heat transfer ($A$) decreased, too.

The industrial fermentations are very sensitive to the variation of media composition, presenting a similar tendency to the one described by the simulation.
Conclusions

Dynamic models for simulation of fermentation processes were developed and implemented in FERMENTA 4.0 software, which includes different equations representing cell growth rate. They are sufficiently general and can be applied to different practical scenarios.

FERMENTA 4.0 software allows process engineers and managers to perform different analyses, in order to select the best alternatives to operate the fermentation process.

In the case study, the sensitivity analysis option allowed studying the effect of initial substrate concentration variations on the efficiency, productivity and final alcoholic grade, as well as the temperature of fermentation on the necessary area of heat exchange.

The simulation results agree closely with typical data obtained on an industrial scale.

REFERENCES


UN LOGICIEL DE SIMULATION DES PROCEDES DE FERMENTATION

Par

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MOTS-clés : Procédé de Fermentation, Modélisation Mathématique,
Production d'Éthanol, Logiciel de Simulation.

Résumé
LA FERMENTATION est une étape clé dans la production d'éthanol et a une incidence élevée dans
l'efficacité du processus de la distillerie. Pour améliorer cette efficacité, une analyse rigoureuse
pour définir le meilleur choix dans les variables de l'opération est indispensable. La simulation du
processus est un moyen reconnu pour faire une telle analyse. Dans cette étude, le logiciel
FERMENTA ® pour la simulation des procédés de fermentation est présenté. Ce logiciel permet la
simulation des modes de fermentation continus et discontinus. Dans le mode de fonctionnement
continu, plusieurs étapes peuvent être considérées. Dans le mode de traitement discontinu, des
solutions alternatives d'alimentation peuvent être étudiées (batch, alimentation par batch selon
différents protocoles). Le modèle mathématique comporte des équilibres transitoires pour la
biomasse, le substrat, l'éthanol, l'oxygène et l'énergie. L'expression cinétique peut être sélectionnée
par l'utilisateur parmi plus de 30 possibilités, en prenant ou pas en compte les facteurs d'inhibition
dans le processus. Les paramètres dans cette équation peuvent être estimés à partir des données
expérimentales. Le résultat est un logiciel utile qui peut être utilisé pour l'analyse de processus de
fermentation de l'industrie et également à des fins académiques. Dans cette communication, le
logiciel est décrit et certaines études de cas utilisées pour démontrer ses possibilités.
UN SOFTWARE PARA SIMULACIÓN DE PROCESOS DE FERMENTACIÓN

Por

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PALABRAS CLAVE: Procesos Fermentativos, Modelación Matemática,
Producción de Etanol, Software de Simulación.

Resumen

LA FERMENTACIÓN es la etapa clave en la producción de etanol y tiene una alta incidencia en la eficiencia total del proceso de la destilería. Para mejorar esta eficiencia se precisa un riguroso análisis para definir la mejor selección de las variables de operación. La simulación del proceso es una vía reconocida para realizar este análisis. En este trabajo se presenta la herramienta software FERMENTA® para simular el proceso de fermentación. Este software herramienta permite simular modos continuos y discontinuos de fermentación. En el modo continuo de operación se pueden considerar varias etapas. En el modo discontinuo se pueden analizar alternativas de alimentación (batch, batch incrementado con diferentes políticas). El modelo matemático incluye balances no-estacionarios para biomasa, sustrato, etanol, oxígeno, energía. La expresión cinética puede seleccionarse por el usuario entre más de 30 posibilidades, tomando ó no en cuenta factores inhibidores en el proceso. Los parámetros en esta ecuación pueden estimarse de los datos experimentales. El resultado es un útil ‘software herramienta’ que puede utilizarse para analizar el proceso de fermentación en la industria y también para propósitos académicos. En este artículo se describe el software y se emplean algunos estudios para mostrar sus posibilidades.
ECO-FRIENDLY COOKING GAS FROM SUGAR MILL WASTE

By
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KEYWORDS: Filter Cake, Digester, Organic Matter, Methanisation, Biogas.

Abstract
IT WAS FOUND that biogas or cooking gas can be produced successfully from sugarcane filter cake. It contains a considerable amount of organic matter in the range of 73% to 77% including 1.8% to 3.0% sugar. After analysing the constituents of the filter cake and after finding its suitability, a laboratory scale study was conducted. As a result it was established that maximum biogas can be produced using filter cake as a feed stock when the concentration of its solids is 6% to 8%; beyond which the production rate decreases. It was also established that average biogas of 0.39 L/d was higher at 8% concentration than with other feed concentrations. After optimising the results, a pilot scale study was conducted during which it was established that the filter cake gives a biogas production of 65% to 75% instead of 50%–52% in the case of cow dung which requires 1:1 dilution to make a slurry for feeding. The filter cake requires 1:1.25 dilution as it contains 26% to 32% dry matter. Recommendations for biogas plant selection and installation are given. The increase in fertiliser value of digested filter cake, power generation, indirect way of helping afforestation, and environmental protection are discussed.

Introduction
About half of the world’s population depends on fire wood for cooking purposes. Water-containing materials from plants and animals contribute to bio-fuels. Such materials should be utilised to keep pace with the growth of biomass, since excessive cutting of woods leads to deforestation and also direct combustion leads to excessive smoke causing air pollution. The gasification is done in two ways. The first is by bio-degradation in which a large amount of biogas is obtained.

The second is thermo-chemical conversion or pyrolysis which yields producer gas comprising carbon monoxide and hydrogen (CO, H₂). The development and utilisation of renewable sources of energy along with conventional sources is essential to meet the growing demand for energy in the world. In particular, among the non-conventional energy sources is ‘biogas’.

In India there are about 500 working sugar mills, crushing about 300 million tonnes of sugarcane, producing about 12 million tonnes of filter cake which is one of the by-products of the sugar industry. This filter cake is being used as fertiliser in and around the sugar mill areas. In some factories, the cane growers do not want to use it as a manure. In such areas it is a great problem for the sugar mills to dispose of the filter cake.

The factory has to spend a large amount for the disposal by engaging lorries or tractors. If it is dumped on public lands, it will affect the environment and the surrounding village people may object to it. If it is not removed from the filter cake yard, the accumulation may sometimes affect the rate of crushing or will lead to stoppage of crushing if the area required for storage is insufficient. If the filter cake produced is not taken by cane growers, the factory has to spend extra money for the disposal and thereby increases the cost of production. In each sugar mill, a canteen is
provided for the employees. The canteen will run around the clock during the crushing season. In the off-season also the canteen has to operate for the preparation of meals, ‘tiffin’, tea, coffee etc.

Fire wood is used as a fuel. A 2500 t cane/d plant utilises about 150–200 t of fire wood per annum. In money value, it will be about $8500. So, to avoid the deforestation for fire-wood, a study on filter cake utilisation for the production of biogas and to increase the fertilising value of filter cake was carried out.

Generally in India, in rural areas, the people cannot rely on LPG (liquefied petroleum gas) for cooking purposes as the availability is very unreliable, Hobson et al. (1981). Only the urban area people are enjoying this benefit. The rural area people in addition cannot afford to use it, because its cost is higher compared to fire wood.

Additionally, firewood is easily available due to deforestation. To some extent, the biogas acts as an eco-friendly bio fuel in rural areas. Biogas can be generated using cow dung in general in rural areas. However, the maintenance cost for cattle has caused the people to abandon it. That is why a number of ‘gobar’ (cow dung) gas plants in the rural areas are not functioning and have been left abandoned.

The outcome of the research resulted in the identification of sugarcane filter cake as a potential alternative source for biogas generation to utilise it in sugar factory canteens as well as in rural areas. Additionally, the fertilising value of digested filter cake improves.

**Filter cake as a feedstock**

Filter cake is a solid residue which is a by-product of sugar industry, Balasubrammaniam and Kasturei Bai (1988). The filter cake has essential nutrients besides containing a considerable amount of organic matter Nunez et al. (1985) and sugar Paturau (1982).

**Table 1—Analysis of sugarcane filter cake (dry basis).**

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Constituents</th>
<th>Content in press mud %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Organic matter</td>
<td>73–77</td>
</tr>
<tr>
<td>2</td>
<td>Organic carbon</td>
<td>40–57</td>
</tr>
<tr>
<td>3</td>
<td>Total solids (T.S.)</td>
<td>26–32</td>
</tr>
<tr>
<td>4</td>
<td>Volatile solids (V.S.)</td>
<td>18–24</td>
</tr>
<tr>
<td>5</td>
<td>Ash</td>
<td>7–11</td>
</tr>
<tr>
<td>6</td>
<td>Moisture</td>
<td>68–72</td>
</tr>
<tr>
<td>7</td>
<td>Sugar</td>
<td>1.8–3.0</td>
</tr>
<tr>
<td>8</td>
<td>pH</td>
<td>4.4–4.8</td>
</tr>
<tr>
<td>9</td>
<td>Nitrogen</td>
<td>2.0–3.5</td>
</tr>
<tr>
<td>10</td>
<td>Phosphorus</td>
<td>0.5–0.78</td>
</tr>
<tr>
<td>11</td>
<td>Potassium</td>
<td>0.28–0.38</td>
</tr>
<tr>
<td>12</td>
<td>Sulfur</td>
<td>1.2–1.4</td>
</tr>
<tr>
<td>13</td>
<td>Calcium</td>
<td>3.0–3.8</td>
</tr>
<tr>
<td>14</td>
<td>Protein</td>
<td>14.5–18.0</td>
</tr>
</tbody>
</table>

Table 1 shows the analysis of sugarcane filter cake, while Table 2 gives the analysis of constituents in the total solids present in the filter cake Nunez (1985).

**Table 2— Constituents of total solids.**

<table>
<thead>
<tr>
<th>Constituents</th>
<th>Quantity %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volatile solids</td>
<td>66.80–70.90</td>
</tr>
<tr>
<td>Ash</td>
<td>30.70–32.80</td>
</tr>
<tr>
<td>Protein</td>
<td>51.88–54.54</td>
</tr>
</tbody>
</table>

Tables 3 and 3A provide data on biogas production from filter cake during different weeks at varying total solids concentration, and Table 4 the methane content of biogas generated from filter cake.
Table 3—Biogas production from filter cake in different weeks at varying total solids concentration.

<table>
<thead>
<tr>
<th>Solid concentration %</th>
<th>Period of digestion (days)</th>
<th>Total biogas production L</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0–7</td>
<td>8–14</td>
</tr>
<tr>
<td>4</td>
<td>3.80</td>
<td>3.40</td>
</tr>
<tr>
<td>6</td>
<td>3.20</td>
<td>3.83</td>
</tr>
<tr>
<td>8</td>
<td>2.40</td>
<td>4.20</td>
</tr>
<tr>
<td>10</td>
<td>0.86</td>
<td>1.10</td>
</tr>
<tr>
<td>12</td>
<td>0.49</td>
<td>0.89</td>
</tr>
<tr>
<td>14</td>
<td>0.23</td>
<td>0.34</td>
</tr>
</tbody>
</table>

Table 3A—Details of biogas production from filter cake.

<table>
<thead>
<tr>
<th>Ex. Pt. No.</th>
<th>Initial volatile solids</th>
<th>pH</th>
<th>Average biogas production L/day</th>
<th>Period of highest biogas production</th>
<th>Highest production L/day</th>
<th>Temp. °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.81</td>
<td>6.9–7.1</td>
<td>0.26</td>
<td>4th–13th</td>
<td>1.8</td>
<td>28–31</td>
</tr>
<tr>
<td>2</td>
<td>4.18</td>
<td>6.9–7.1</td>
<td>0.35</td>
<td>7th–24th</td>
<td>1.8</td>
<td>28–34</td>
</tr>
<tr>
<td>3</td>
<td>5.58</td>
<td>6.9–7.1</td>
<td>0.39</td>
<td>12th–30th</td>
<td>1.1</td>
<td>28–34</td>
</tr>
<tr>
<td>4</td>
<td>6.95</td>
<td>6.9–7.2</td>
<td>0.19</td>
<td>16th–32nd</td>
<td>1.9</td>
<td>28–34</td>
</tr>
<tr>
<td>5</td>
<td>8.31</td>
<td>6.9–7.1</td>
<td>0.18</td>
<td>20th–35th</td>
<td>1.9</td>
<td>28–34</td>
</tr>
<tr>
<td>6</td>
<td>9.70</td>
<td>6.9–7.2</td>
<td>0.08</td>
<td>26th–37th</td>
<td>1.7</td>
<td>28–34</td>
</tr>
</tbody>
</table>

Table 4—Methane content of biogas generated from filter cake.

<table>
<thead>
<tr>
<th>Solid concentration %</th>
<th>Methane (CH₄) content %</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>67.5</td>
</tr>
<tr>
<td>6</td>
<td>70.8</td>
</tr>
<tr>
<td>8</td>
<td>71.8</td>
</tr>
<tr>
<td>10</td>
<td>70.3</td>
</tr>
<tr>
<td>12</td>
<td>64.8</td>
</tr>
<tr>
<td>14</td>
<td>64.1</td>
</tr>
</tbody>
</table>

Experimental aspects Lakshmanam et al. (1990)

Volume of biogas
The generated biogas was measured at a fixed time by an electronic gas meter.

Moisture and total solids
By evaporating the moisture of a known weight of sample in an air-oven at 105°C, the loss of weight of sample was calculated as moisture and the remaining as solid concentration.

Ash and volatile solids
By ignition of a known quantity of sample in a muffle furnace at 550°C for one hour, the ash and volatile solids were determined.

Protein
Protein was estimated by Kjeldahl’s nitrogen analysis multiplying total nitrogen by a factor of 6.25.

pH
By using a digital type pH meter.
Determination of methane
By gas chromatography (porapak-Q column) with hydrogen as a carrier.

Biogas production from filter cake

Procedure
Cattle dung and water in the ratio of 1:1 are first mixed in a tank and then the mixture
(slurry) is allowed to pass through the inlet into the digester. A strainer (sand catcher) has been
provided to prevent the sand particles from entering the digester. The slurry ferments and produced
biogas collects in the gas holder or in the gas storage dome, depending on the design of the plant.
Biogas is drawn from the plant through a pipeline directly to the points of use. To drain out the
condensed water in the pipeline, a drain valve has been provided. Daily, after the gas has been used,
the digester is freshly filled with slurry, taking care that an equal amount of digested slurry comes
out from the digester.

Results and discussions
Tables 1 and 2 summarise the chemical composition of the used filter cake.
It should be pointed out that the dry substance of filter cake is 26%–32% higher than that of
cow dung (18%) requiring dilution for efficient biogas production.
Table 3 indicates that the biogas production increases from 4% to 8% dry substance,
culminating at 6% with 22.40 L biogas. Beyond 8% solids, the biogas production decreases.
However, during the first week of operations, the highest biogas production was achieved with feed
of 4% solids, which gradually changed during the following weeks (2 to 6) in favour of 6% and 8%
feed solids.
The average biogas production of 0.39 L/d was reached at 8% feed concentration. Highest
methane production was observed at 8% solids. The above results indicate the potential of filter
cake as feed stock for biogas generation.

Pilot scale studies
In the pilot scale studies, a 4 cubic metre capacity digester was used. Initially, the seed
development was done by charging cow dung slurry (by mixing one part of cow dung with one part
of water) to build the essential population of methanogenic bacteria. After the stabilisation of the
methanogenic operation, the bacterial population was adequate as indicated by the sufficient
methane production. Filter cake slurry prepared by mixing one part of filter cake with 2.5 parts of
water was added. Biogas production was found to be 0.7–0.8 m³/d with about 50%–52% methane
during the first week of initial feeding with cow dung slurry. The gas production increased to a
steady level of 2 m³/d after a week of feeding with filter cake. After three months of continuous
feeding with filter cake, biogas production increased to 2.4–2.6 m³/d. It was observed that, after
charging with filter cake, the methane content of biogas gradually increased from 50%–52% with
cow dung to 65%–75% with filter cake slurry.
Initially, the Karnataka Sugar Institute, Belgaum has commenced a trial with a 4 m³ gobar
gas plant in a near-by sugar mill. After successful completion of the trial, it recommended to all the
cooperative and public sector sugar mills to put up a biogas plant with capacities varying from
60–75 m³/d for canteen cooking purposes.
Similarly, the Institute has helped the cane growers in and around the mills in the
cooperative as well as public sector sugar mills. In addition, it has helped to set-up 3–4 m³/d
capacity small plants in the rural areas. Now, there are about 100 industrial type biogas plants with
a capacity of 60 m³/d in 100 sugar mills including cooperative, public and private sector sugar mills
in India. About 200 of 4 m³/d capacity domestic type biogas plants are now operating near sugar
mills in India utilising filter cake as a feedstock for the production of biogas. Thus the sugar mills in
India are helping the rural people to enjoy the benefit of biogas for safe cooking by avoiding the use
of firewood.
**Tips for biogas plant installation**

1. Select an elevated dry and open area exposed to sunshine for a greater part of the day.
2. It should be near the kitchen.
3. The ground water level should be minimum 2 metres.
4. There should not be any drinking water well or hand pump within the range of 15 metres from the gas plant.

**Capacity**

1. Each kg of filter cake produces 0.05–0.06 m³ of bio gas.
2. The gas required for cooking per day per person is estimated to be 0.3 m³.
3. For a sugar factory canteen, the gas requirement for some 250 persons is 75 m³.

**Selection of bio-gas plants** Malik et al. (1995).

1. Floating gas holder, commonly called KVIC type (Khadi & Village Industries Commission).
2. Fixed dome called Janatha type.
3. Pragati model.
4. Modified fixed dome called Deenabandhu model.
5. KVIC type plant having digester made of angle iron and polyethylene sheet called Ganesh model.
6. KVIC type plant having digester made of pre-fabricated ferro-cement segments.
7. KVIC type plant made with fibre glass, reinforced plastic.
8. The floating type drum was found to be more efficient compared to other types. The floating drum should be rotated once or twice a day so that a stirring effect will be created. If the plant is in regular use, 1:1 ratio of urea and di-ammonium phosphate added once in a fortnight will enhance the growth of the methanogenic bacteria. Diluted molasses or effluent can also be used to enhance gas production. Generally, the retention time varies from 30–50 days. Instead of mild steel, fibre glass can also be used for the drums to avoid corrosion. If a stirring arrangement is provided, the retention time is reduced. The retention time may vary from digester to digester. If a higher production rate is required, the rate of feeding may be increased. Generally, feeding should be in the morning.
9. The fixed dome plant should strictly be made by well-trained master masons who have the experience of constructing such plants; material quality is of importance (bricks, cement) for avoiding cracking and gas leaks Malik et al. (1997).

**Components of a plant**

A biogas Plant consists of the following parts:

1. Mixing tank and inlet.
2. Digester.
3. Gas holder or gas storage dome.
4. Outlet and compost pit.
5. Gas main outlet and valve, pipelines, water fittings, gas stove lamp and similar appliances suitable for biogas.

**Selection of depth of digester**

The depth or volume of the digester is determined by the retention period which depends upon the average ambient temperature of the area. Commonly these are:

1. Plants based on 30 days retention period.
2. Plants based on 55 days retention period.
Cost of the plant
Cost of installation varies according to the type and size of the plant. On average, a FRP model is 5% more and a ferro-cement digester model is 10% less than the KVIC model.

The cost of the plant will vary depending on location. In India, the cost of the floating drum type model with 60 m³ capacity about $6000–7000.

Facilities provided by the State and Central Government of India

The State Energy Development Corporation under the control of State Governments and the Ministry of Non-Conventional Energy Sources, Government of India are providing facilities for promotion, construction, after sales services and repairs. It also provides subsidy facilities.

The State Government and KVIC (Kadhi and Village Industries Commission) have created biogas cells at the state and district level for providing technical guidance, supervision in the construction, maintenance of plant and arrangement, inputs like cement, steel and institutional finances providing post installation servicing facilities etc.

Power from biogas

One cubic metre of biogas produces 250 watts of electricity (with the aid of oil engine and generator). It has increased thermal efficiency and calorific value as compared to biogas from cow dung. The biogas can effectively be used for cooking, running farm machinery and also for lighting farm houses.

Fertilising values

The digested filter cake which leaves the digester is rich in nitrogen, phosphorus and potassium. Field trials with sugarcane comparing raw filter cake vs. digested filter cake showed increased yields from digested filter cake.

There is also no wax and sulfur in digested filter cake. It was also discovered that digested filter cake acts as a weedicide. When using digested filter cake for wetting agricultural wastes in bio-manuring, the methanogenic bacteria act as catalysts in decomposing the organic residue. The digestion period is also reduced by about 40%.

Conclusion

Biogas from filter cake is a clean and cheap gaseous fuel. It contains 65%–75% methane which is combustible and it is produced by digestion. The fertilising value of the filter cake does not diminish but rather enhances during the digestion process.

Thus, the filter cake converts by digestion to two useful products, fuel and fertiliser. It should be handled with care (fire hazard) and it saves on cooking time.

It is a non-conventional energy source. The Central and State Governments are encouraging this program.

Biogas is an eco-friendly, non-fossil fuel replacing firewood for cooking, thus helping to prevent deforestation for the benefit of the environment.

Acknowledgement

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REFERENCES


PRODUCTION DE BIOGAZ A PARTIR DES ÉCUMES D'UNE USINE SUCRIERE

Par

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MOTS-CLÉS: Ecumes, Digesteur, Matiere Organique, Methanisation, Biogaz.

Resumé
Il a été constaté que du biogaz ou gaz de cuisson peut être produit avec succès à partir des écumes produites dans les usines sucrières. Elles contiennent une quantité considérable de matière organique de 73 à 77% y compris le sucre de 1.8 à 3.0%. Après l'analyse des constituants des écumes et l'identification de leur utilité possible, une étude à échelle de laboratoire a été effectuée. Il a été ainsi établi qu’un taux maximal de biogaz peut être produit à partir des écumes quand la concentration des solides est de 6 à 8%. Après ce seuil le taux de production diminue. Il a également été établi qu’une production de biogaz de 0.39 L/jour était supérieur à 8% de concentration qu’aux autres taux utilisés. Après optimisation des résultats, une étude pilote a été menée au cours de laquelle il a été établi que les écumes donne une production de biogaz de 65 à 75% au lieu de 50–52% dans le cas de fumier de vache qui nécessite une dilution de 1:1 pour faire une boue pour l'alimentation. Les écumes nécessitent une dilution de 1:1.25 car elles contiennent 26 à 32% de matière sèche. Des recommandations pour la sélection d'usine de production de biogaz et les installations connexes sont énoncées. L'augmentation de la valeur en termes d'engrais des écumes fermentées, la production d'énergie, le moyen indirect d'aider le boisement et la protection de l'environnement sont abordés.
GAS PARA COCINAR ECOAMIGABLE A PARTIR DE RESIDUOS DE INGENIOS AZUCAREROS

Por

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PALABRAS CLAVE: Torta de Filtros, Digestor, Materia Orgánica, Metanización, Biogás.

Resumen

Se encontró que el biogás ó gas para cocinar puede ser producido exitosamente a partir de tortas de los filtros de la cana de azúcar. Contienen una cantidad considerable de materia orgánica, en el rango de 73 a 77%, incluyendo de 1.8 a 3.0% de azúcar. Después de analizar los constituyentes de las tortas de los filtros y después de encontrar su conveniencia, se realizó un estudio a escala de laboratorio. Como resultado se estableció que un máximo de biogás puede producirse empleando torta de los filtros como materia prima, cuando la concentración de los sólidos es de 6–8%, más allá de estos valores decrece la producción. Se estableció, así mismo, que el promedio de biogás de 0.39 L/d era mayor a8% de concentración que a cualquier otro valor. Después de optimizados los resultados, se realizó un estudio a escala piloto, en el cual se comprobó que la torta de filtros rinde una producción de biogás de 65% a 75% en lugar de 50–52% que se obtiene con excretas de vacas, que requieren una dilución 1:1 para lograr la consistencia del fango de alimentación. La torta de los filtros requiere una dilución de 1:1.25 ya que contiene 26 a 32% de materia seca. Se brindan recomendaciones para la selección e instalación de las plantas de biogás. Se discute en el valor fertilizador de la torta de los filtros digerida, la generación de energía, vías indirectas de forestación y la protección ambiental.
AN UP-DATE OF COGENERATION EFFICIENCY AND ECONOMIC INDICATORS USING MODERN COMMERCIAL TECHNOLOGIES

By

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KEYWORDS: Ethanol, Cogeneration, Production Cost.

Abstract

A SCENARIO considering capacity, parameters and commercialisation prices for cogeneration systems equipment was carried out, different Brazilian manufacturing costs were considered, and related data presented in tables and figures. Using the Gate-Cycle software, cogeneration plant schemes were modelled for different ethanol distillery capacities. Using energy balances and equipment cost data, the electricity generation cost was calculated for each of the evaluated scenarios. As a result of the evaluated scenarios, indicators such as: surplus electricity index, energy utilisation factor and exergy efficiency are presented. Recommendations are presented about the most profitable scenarios considering present electricity commercialisation prices of about 56.52 US$/MWh and two ethanol market price levels: 0.30 and 0.17 USD$/L.

Introduction

According to the Ministry of Agriculture, Livestock and Supply (MAPA), a government agency responsible for the registration of the mills and distilleries installed in Brazil, 434 plants crushing 495 million tonnes of sugarcane per year were in operation in the 2007/2008 harvest. Sixteen were used for sugar production only, 167 for ethanol production and the 251 remaining plants produced both sugar and ethanol (MAPA, 2009). Most of the large plants are located in the state of São Paulo, where almost two-thirds of the Brazilian ethanol is being produced (Goldemberg, 2008).

Until 1980, sugar and ethanol plants in the state of São Paulo were using boilers with pressure between 1.2 and 2.2 MPa and were purchasing 40% of the electric power they consumed. By 1990, with the replacement of old boilers and turbines, the average steam pressure in these plants had reached 2.2 MPa, with temperatures of 300°C, levels which made the plants self-sufficient with regard to their electric power needs, and in some cases produced a small surplus for sale.

Today, these boilers are being substituted by high-pressure boilers operating in the range of 6 up to 12 MPa and, in some cases, the plant capacity is increased; as a result, energy efficiency is being increased and there is in fact a large electricity surplus that is supplied to the grid. Presently, it is assessed as approximately 1400 MW, with a forecast for 2020 of 14 400 MW (Unica, 2009).

Therefore, research about how these changes affect the production costs of the final products obtained in the distilleries (electricity surplus and ethanol) and what will be the resulting efficiency increase for the whole plant is an important aspect. By carrying out simulations using commercial software and thermodynamic tools, this study intends to determine the available surplus electricity, the global efficiency and the final production cost of the main products of an autonomous distillery, considering increases in the plant mill capacity and steam parameters. It also evaluates, from an economic point of view, each one of the alternatives proposed, considering the investment values, the operational and maintenance costs, and the revenues from hydrated ethanol and electricity commercialisation.
Finally, an analysis is carried out for the determination of the specific investment required per tonne of crushed cane, the electricity generation cost, and the NPV obtained as a function of the plant capacity and steam parameters utilised, as well as for different hydrated ethanol and electricity commercialisation prices.

**General aspects**

Bioethanol producers establish the minimum price for their product considering two conditions: a) to cover the production costs, which obviously include raw material and plant operational costs, as well as capital costs corresponding to production investments; and b) be equal to, or higher than the price that could be obtained if the raw materials were used in the best manufacturing alternative. Sugar and molasses are among the alternative products that can be obtained from sugarcane. The second one is a by-product of the sugarcane industry that has value as an industrial input or as animal feed (BNDES and CGEE, 2008).

Indeed, the estimation of the ethanol production costs in Brazil is quite a difficult task. First, it is important to mention that this cost varies significantly in different production regions, due to the differences in productivity and cost of sugarcane production. Not only does the productivity vary, but also the cost of sugarcane production changes according to the harvest and transportation technologies. Second, estimating the cost of the sugarcane is crucial to the ethanol cost estimation. Most studies regarding Brazilian ethanol have estimated sugarcane production cost at $10 dollars per tonne, which gives a cost of roughly $0.10 per litre of ethanol. However, this cost is considered by De Almeida et al. (2007) to be underestimated.

Figure 1 shows the rise of hydrated ethanol production in Brazil between 2003 and 2008 and the corresponding prices for producers (excluding taxes).

![Fig. 1—Brazilian hydrated ethanol production and average prices for producer excluding taxes (UDOP, 2009 and CEPEA, 2009).](image)

Having in mind the previously mentioned aspects, the estimation of the real ethanol production cost for the different installed plants is a very important aspect in the modernisation and expansion of the ethanol industry.

Equally, the prospect of selling electric power to public utility concessionaires requires knowledge of the real electricity production cost to calculate the economic impact of surplus electricity commercialisation in the economic balance of the distillery plant.

**Process description**

During ethanol production from sugarcane in an autonomous distillery (i.e., not annexed to a sugar mill), the feedstock is washed, crushed and milled to extract the sugarcane juice and in doing so a co-product is generated (bagasse). The sugarcane juice is transformed into ethanol according to
the following stages: juice treatment, concentration and sterilisation; fermentation; distillation and dehydration. The sugarcane bagasse (50% moisture) is burnt in boilers for generation of thermal and electrical energy demanded by the whole plant (see Figure 2).

![Diagram](image)

**Fig. 2—Physical structure of autonomous distillery (Adapted from Higa, 2003).**

**Evaluated alternatives**

Considering the great diversity of autonomous distilleries that exist in Brazil in relation to their milling capacity and the level of technological development of their cogeneration systems, five different autonomous distilleries with different steam parameters and capacities were considered. Their simulation was carried out, considering the parameters presented in Table 1, using the Gate-Cycle software.

**Table 1—Parameters adopted for the process simulation.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cogeneration plant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atmospheric air temperature</td>
<td>25</td>
<td>°C</td>
</tr>
<tr>
<td>Atmospheric air pressure</td>
<td>101.3</td>
<td>kPa</td>
</tr>
<tr>
<td>Steam pressure</td>
<td>4.2–12</td>
<td>MPa</td>
</tr>
<tr>
<td>Steam temperature</td>
<td>420–520</td>
<td>°C</td>
</tr>
<tr>
<td>Condensing pressure</td>
<td>20</td>
<td>kPa</td>
</tr>
<tr>
<td>Bagasse moisture content</td>
<td>50</td>
<td>%</td>
</tr>
<tr>
<td>Sugarcane fibre content</td>
<td>14</td>
<td>%</td>
</tr>
<tr>
<td>Bagasse – Low Heating Value (LHV)</td>
<td>7560</td>
<td>kJ/kg bagasse</td>
</tr>
<tr>
<td>Boiler thermal efficiency</td>
<td>88</td>
<td>%</td>
</tr>
<tr>
<td>Steam turbines isentropic efficiency</td>
<td>80</td>
<td>%</td>
</tr>
<tr>
<td>Pump isentropic efficiency</td>
<td>85</td>
<td>%</td>
</tr>
<tr>
<td>Electric generator efficiency</td>
<td>96</td>
<td>%</td>
</tr>
<tr>
<td>Process electric power consumption</td>
<td>12</td>
<td>kWh/tc</td>
</tr>
<tr>
<td>Cogeneration plant auxiliary equipment power consumption</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mills</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mills capacity</td>
<td>180–580</td>
<td>tc/h</td>
</tr>
<tr>
<td>Inlet steam pressure</td>
<td>2.2</td>
<td>MPa</td>
</tr>
<tr>
<td>Process steam pressure</td>
<td>250</td>
<td>kPa</td>
</tr>
<tr>
<td>Mechanical power demand of cane preparation and juice extraction</td>
<td>16</td>
<td>kWh/t of cane</td>
</tr>
<tr>
<td>Steam turbines isentropic efficiency</td>
<td>70</td>
<td>%</td>
</tr>
<tr>
<td>Process steam demand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process steam pressure</td>
<td>250</td>
<td>kPa</td>
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<tr>
<td>Process steam temperature</td>
<td>124.7</td>
<td>°C</td>
</tr>
<tr>
<td>Process steam consumption</td>
<td>388</td>
<td>kg/tc</td>
</tr>
<tr>
<td>Ethanol yield</td>
<td>86</td>
<td>l/tc</td>
</tr>
</tbody>
</table>

*Based on LHV of mill wet bagasse
**Calculated for each case using the modelling software Gate-Cycle.
With respect to the electric power consumed by the different process stages (juice treatment, concentration, illumination, etc.), there are slight distinctions between processes, but all of them are around 12 kWh per tonne of processed sugarcane (BNDES and CGEE, 2008). This index was complemented with the electric power consumption of pumps and auxiliary equipments in the cogeneration systems, calculated using the Gate-Cycle software.

**Performance indexes**

**Thermodynamic assessment**

Some thermodynamic performance indexes presented by Horlock (1987) and Lora et al. (2006) (Eqs. (1), (2), (3) and (4)) have been considered and calculated for the different alternatives analysed in this paper. The calculated values are shown in Table 2.

**Energy fuel utilisation (EUF)**

This index is based on the first law of thermodynamics and allows calculating the energy efficiency of a cogeneration plant.

\[
EUF = \frac{W_e + Q_u}{m_f \cdot LHV}
\]

where \( W_e \) is the net electricity power output, \( Q_u \) is the useful heat rate delivered to the process and \( E_f \) is the fuel energy consumed, calculated as the product of bagasse mass flow (\( m_f \)) and its low heating value (LHV).

**Exergetic efficiency (\( \eta_{ex} \))**

This index allows calculating the cogeneration efficiency based on the second law of thermodynamics, using exergy as a measure of the ‘real’ value, i.e., availability of an energy stream. Instead of using the process heat, this index uses the process consumed exergy, and the fuel energy is also substituted by its exergy.

\[
\eta_{ex} = \frac{W_e + B_p}{B_f}
\]

where \( B_p \) is the exergy of the heat delivered to the process (as steam) and \( B_f \) is the exergy of the consumed fuel (bagasse).

**Global exergetic efficiency (\( \eta_g \))**

This indicator is obtained by dividing the sum of the exergy of the hydrated ethanol and the surplus electricity, by the exergy contained in the sugarcane (Eq. 4). It is a measure of the level of utilisation of the energy contained in the sugarcane.

\[
\eta_g = \frac{E_{HE} + E_{el.ex}}{E_c}
\]

where \( E_{HE} \) is the exergy content of hydrated ethanol; \( E_{el.ex} \) the surplus of electricity and \( E_c \) the sugarcane exergy.

The sugarcane exergy content (\( E_c \)) is calculated by the Eq. 4.

\[
E_C = E_B + E_{BC}
\]

where \( E_B \) is the bagasse exergy content and \( E_{BC} \) the sugarcane juice exergy content.
Thermodynamic evaluation results

Figure 3 shows that, for each mill capacity, when the steam parameters are increased from 4.2 up to 12 MPa the surplus electricity per tonne of sugarcane crushed is increased by approximately 46%, while the exergetic efficiency of the plant is increased by 17%. It also shows the influence of the steam parameters and the distillery capacity in global exergetic efficiency of the plant. When these two factors are increased, this index is increased by approximately 3% as a consequence of the better use of the sugarcane energy content. To accomplish the necessary process steam consumption for each evaluated capacity scenario, it was necessary to consider the utilisation of turbines with different sizes and extraction/steam flow ratios. As a consequence, different values of surplus electricity per tonne of crushed cane were obtained, showing no logical tendencies. So, this is the reason why, for crushing rates of 180 tc/h, the index of electricity surplus is higher than for plants with capacities of 580 tc/h.

For steam parameters of 12 MPa, an increase of 5, 8, 9 and 11% in the global exergetic efficiency of the plant is obtained, respectively of the considered plant capacity levels.

From a thermodynamic point of view, Figure 3 shows that the better alternative, to be considered as a first option, is a distillery with steam parameter of 12 MPa/520°C and a plant capacity of 580 tc/h. A distillery with steam parameters of 8 MPa/510°C and a plant capacity of 580 tc/h can be considered as a second alternative. However, to validate the obtained result, it is necessary to carry out the economic evaluation of these alternatives.

Economic assessment

Considering that in the autonomous distillery, analysed multiple products with aggregated value (Electricity and Ethanol) are obtained, it is necessary to distribute the total costs of the plant and of the sugarcane in a rational way among them, as they will influence directly on each final product cost.

Therefore, to obtain the final production cost of electricity and ethanol, it is necessary to select the more rational cost allocation method for the products. The allocation method must generate product costs that reflect the real costs involved in its production, without overcharging
one of the products (Escobar et al., 2009). In this work, the cost allocation method applied is based on the Second Law of Thermodynamics, using the so-called thermo-economic analysis, an approach that combines the exergy concept with economics, seeking for cost distribution (Lora et al., 2008). This methodology allows allocation of the input costs, as well as the investment, operation and maintenance costs of the equipment for ethanol and electricity production in dependence of the consumed exergy for its production. Figure 4 shows a schematic representation of the methodology employed for the thermo-economic assessment.

![Thermo-economic assessment methodology flow scheme.](image)

**Cost formation**

The distillery system can be considered as a system or a set of subsystems, that exchange flows (mass and energy) among themselves and between them and the environment. This information can be converted into financial or cost flow (C). The cost composition in the distillery system can be generally represented by equation (5), where the units are expressed in financial units per unit of time ($/h). In Eq. (5) the first member is the sum of input flows and the second member the outputs flow.

\[
C_c + Z_{pp} = C_{\text{ethanol}} + C_{\text{electricity}}
\]  

(5)

The input costs of the plants are the cost of sugarcane (\(C_c\)) and the fraction referred to depreciation, operations and maintenance costs of the equipment that compose the global plant (\(Z_{pp}\)). The products or output of the equation are the cost allocated to ethanol (\(C_{\text{ethanol}}\)) and the electric power (\(C_{\text{electricity}}\)). For computing the unitary costs of electricity production (\(c_{\text{electricity}}\)) and ethanol (\(c_{\text{ethanol}}\)), that are expressed in $/kWh and $/L, it is necessary to write the Eq. (5) in the form of Eq. (6).

\[
C_c + Z_{pp} = c_{\text{ethanol}} V_{\text{ethanol}} + c_{\text{electricity}} P_{\text{electric}}
\]

(6)

where \(V_{\text{ethanol}}\) is the hourly produced hydrated ethanol and \(P_{\text{electric}}\) is the net electric power expressed in L/h and kW, respectively.

The equipment costs that compose the plants in the different analysed scenarios were obtained from national equipment manufacturers and adapted to necessary capacities using a scaling factor. During the determination of the investment costs, some of the items necessary for the economic analysis couldn’t be determined. So it was necessary to set percentages in relation to the acquisition price of different equipment (Table 2).

**Table 2**—Percentage values used of equipment costs used for auxiliaries, installation, civil construction and O&M during investment cost calculation (Barreda, 1999).

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installation</td>
<td>20</td>
<td>%</td>
</tr>
<tr>
<td>Pipes</td>
<td>10</td>
<td>%</td>
</tr>
<tr>
<td>Instrumentation and control</td>
<td>6</td>
<td>%</td>
</tr>
<tr>
<td>Electrical equipment and material</td>
<td>10</td>
<td>%</td>
</tr>
<tr>
<td>Civil construction</td>
<td>15</td>
<td>%</td>
</tr>
<tr>
<td>Operating &amp; maintenance</td>
<td>5</td>
<td>%</td>
</tr>
</tbody>
</table>
The annual interest rate considered was 8%, while the amortisation period for the equipment was assumed to be 10 years.

The autonomous distilleries specific investments for different steam parameters and plant capacities are presented in Figure 5.

![Figure 5](image)

Fig. 5—Specific investment required for ethanol distilleries as a function of steam parameters and plant capacity.

With the values obtained from Figure 5, it’s possible to calculate the production cost for the electricity and ethanol in different distilleries, in accordance with the productive purpose of each subsystem that comprises the global plant and the consumed and/or produced exergy in each stage. A schematic representation of the formation and cost sharing process in a distillery is shown in Figure 6.

![Figure 6](image)

Fig. 6—Cost splitting and allocation scheme in a distillery system.

The subsystem 1 (Sub1) of Figure 6 represents all the components of the plant that supply exergy to the cogeneration cycle (pumps, boilers, deaerator, etc.), while the subsystem 2 (Sub2) represents the components that consume exergy (turbogenerators, condensers, mechanical drives). The subsystem 3 (Sub3) represents the ethanol production stages (heating, evaporation, cooling, fermentation and distillation). This allows one to follow the costs formation process of the main products of the plant (ethanol and electricity).

The Eq. (6) shows that, in a multiproduct plant, the main product costs are depending one of the other; therefore, it is necessary to allocate the sugarcane cost in a proportional way for the global system, avoiding overcharging the cost of one of the obtained products. When the bagasse cost is considered zero in the cogeneration systems, as is usually done due to its byproduct nature, the sugarcane cost will be charged fully to the sugarcane juice obtained in the mills, having as a consequence that the ethanol cost will be higher, while the electricity cost will be lower than the real cost.

Figure 7 shows the dependence of the unitary economic cost for electricity and hydrated ethanol calculated for a distillery with steam parameters of 8 MPa/510°C and a capacity of 480 tc/h.
This means that, when the market price of the ethanol grows, this can economically compensate the decrease in the commercialisation price of surplus electricity, a phenomenon known as internal cost allocation. To calculate the cost of the generated electricity, it is necessary to estimate in advance the hydrated ethanol production cost, as this is the main distillery product. The average unit cost calculated for hydrated ethanol in the different plant capacities was 0.18 USD$/l. Electricity production costs for all the evaluated scenarios starting from this average ethanol cost are presented in Figure 8.

Figure 8 shows that the highest values of electricity cost production are obtained for steam parameters of 4.2 MPa/420°C with values of 52.60, 49.56, 43.53, 38.74 and 33.03 USD$/MWh for each one of the considered plant capacities.

However, it’s possible to obtain a reduction of these values by approximately 13% through the increase in the steam parameters from 4.2 MPa up to 6 MPa, and a reduction of 6% by the implementation of steam parameters of 8MPa instead of 6.0 MPa.

When the steam parameters are increased from 8 up to 12 MPa, the electricity generation cost increases by approximately 8%, due to the higher investment in some plant components. In this case, the boiler cost increases approximately 31%.

When steam parameters are increased from 4.2 up to 6 MPa, the boiler costs increase by 22% and, in the case when passing from 6 up to 8 MPa, this cost increases is 9%, approximately.

It is observed in Figure 8 that, from an economic point of view, the steam parameters of 12 MPa do not represent significant advantages for the electricity cost generation, different from the results obtained when using only the thermodynamic analysis.
Finally, as a complement of the obtained results, cash flow analyses were performed for the determination of the economic attractiveness of the considered scenarios. The Net Present Value (NPV) was used as an economic feasibility indicator. For calculation, an IRR of 15% was assumed representing the minimum attractiveness rate, a value assumed by investors based on market conditions. With the increase in the IRR value, the economic attractiveness of some of the evaluated scenarios could be reduced, especially the ones, shown in Figure 10, with lower ethanol market prices.

Taxes and discount rates adopted for this work during cash flow analysis are presented in the Table 3.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity sale price</td>
<td>56.57</td>
<td>USD$/MWh</td>
</tr>
<tr>
<td>Hydrated ethanol sale price</td>
<td>0.17–0.30</td>
<td>USD$/l</td>
</tr>
<tr>
<td>Industrial electricity price – buying</td>
<td>98.6</td>
<td>USD$/MWh</td>
</tr>
<tr>
<td>Brazilian taxes ICMS, IPI, PIS, COFINS</td>
<td>18</td>
<td>%</td>
</tr>
<tr>
<td>Brazilian taxes IRPJ / CSLL</td>
<td>35</td>
<td>%</td>
</tr>
<tr>
<td>Planning time horizon</td>
<td>20</td>
<td>years</td>
</tr>
<tr>
<td>Financed fraction of the investment</td>
<td>40</td>
<td>%</td>
</tr>
<tr>
<td>Financing system</td>
<td>Price</td>
<td></td>
</tr>
<tr>
<td>Interest rate</td>
<td>8</td>
<td>%</td>
</tr>
<tr>
<td>Internal rate of return (IRR)</td>
<td>15</td>
<td>%</td>
</tr>
</tbody>
</table>

ICMS: Value-Added Tax (V.A.T.) on Sales and Services  
IPI – Excise Tax  
PIS – Social Integration Program Tax  
COFINS – Social Security Financing Contribution  
IRPJ – Company Income Tax

Figure 9 shows the main NPV obtained in the different evaluated scenarios. It is observed that, for fixed market prices of ethanol and electricity of 0.30 USD$/l and 56.56 USD$/MWh, the attractiveness of the investment increases when the steam parameters go from 4.2 up to 8 MPa and the plant capacity is in the range of 380–580 tc/h.

Fig. 9—Specific Net Present Value for a distillery as a function of steam parameters and plant capacity for ethanol and electricity market prices of 0.30 USD$/l and 56.57 USD$/MWh respectively.

In spite of allowing a higher global efficiency of the plant, the steam parameters of 12 MPa present a lower economic attractiveness than the steam parameters of 8 MPa, which need a lower initial investment.
In the cash flow analyses, another scenario was considered with ethanol and electricity prices of 0.17 USD$/l and 56.57 USD$/MWh. Main results are shown in Figure 10. As shown, the economic feasibility of autonomous distilleries in the range of 180 – 280 tc/h presents high dependence from the ethanol market price. This is not valid for distilleries in the range of 380 up to 580 tc/h with steam parameters of 8 MPa. It’s observed that the increase in the steam parameters for maximising the electricity surplus and choice of the plant capacity are main factors for assuring the economic feasibility of ethanol plants when the market price of ethanol and electricity is variable.

![Figure 10](image_url)

**Fig. 10—Specific Net Present Value for a distillery as a function of steam parameters and plant capacity for ethanol and electricity market prices of 0.17 USD$/l and 56.57 USD$/MWh respectively.**

**Conclusions**

The market price of electricity can compensate possible oscillations in ethanol market prices, so the internal cost allocation gives certain flexibility in reaching economic feasibility during autonomous distillery investment planning and operation.

Actually, the steam parameter that allows obtaining the lowest electricity generation cost is 8 MPa, in spite of steam parameters of 12 MPa resulting in higher plant global efficiency.

The economic feasibility of autonomous distilleries is strongly dependent on the steam parameters adopted for the cogeneration plant, mill capacity and market prices of ethanol and electricity. The increase in the plant capacity enables a higher economic attractiveness.

Thermo-economics, through exergy flows evaluation, is a powerful tool for cost allocation in autonomous distilleries, allowing to obtain final product cost that reflects the process of cost formation in the plant.

**Acknowledgements**

The authors would like to acknowledge the Brazilian equipment manufacturers Dedini Industrias de Base S.A, Texas Turbines, Equipalcool, HPB/Sermatec, NG Metalurgica and TGM for supplying process and cost equipment data.

The authors acknowledge also the funding agencies CAPES, CNPq and FAPEMIG for the financial support for this study through Ph.D and research productivity grants.

**REFERENCES**


UNE MISE À JOUR DE L'EFFICACITÉ DE COGÉNÉRATION ET INDICATEURS ÉCONOMIQUES À L'AIDE DE TECHNOLOGIES COMMERCIALES MODERNES

Par

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MOTS-CLES: Éthanol, Cogénération, Coût de Production.

Résumé

UN SCENARIO tenant compte des capacités, des paramètres et des prix de commercialisation des équipements pour des systèmes de cogénération a été effectué; des différents coûts de fabrication de source brésilienne ont été examinés et les données y relatives sont présentées par le biais de tableaux et des graphiques. A l'aide du logiciel Gate-Cycle des unités de cogénération ont été modélisées pour des distilleries d'éthanol de capacités différentes. Utilisant les balances énergétiques et les données sur les coûts des équipements, le coût de la production d'électricité a été calculé pour chacun des scénarios évalués. À la lumière des résultats des scénarios évalués, les indicateurs tels que: indice de surplus d'électricité, facteur de l'utilisation d'énergie et l'efficacité énergétique sont présentés. Les recommandations issues des scénarios les plus rentables sont présentées tenant compte des prix actuels de commercialisation de l'électricité d'environ 56.52 $ US/MWh et deux niveaux de prix d'éthanol: 0.30 et USD 0.17 $ / L.

UNA ACTUALIZACIÓN DE LA EFICIENCIA DE LA COGENERACIÓN Y LOS INDICADORES ECONÓMICOS, EMPLEANDO TECNOLOGÍAS COMERCIALES MODERNAS

Por

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PALABRAS CLAVE: Etanol, Cogeneración, Costo de Producción.

Resumen

SE ELABORÓ un escenario considerando capacidades, parámetros y precios de comercialización para equipos de sistemas de cogeneración, se consideraron diferentes costos de manufactura brasileñas y datos relacionados presentados en tablas y figuras. Empleando el software ‘Gate-Cycle’ se modelaron esquemas de plantas de cogeneración para diferentes capacidades de destilación de etanol. Se calculó el costo de generación de electricidad para cada escenario evaluado empleando datos de balances de energía y costos de equipos. Como resultado de la evaluación de los escenarios se presentan indicadores como el índice de energía sobrante, el factor de utilización de energía y la eficiencia energética. Se ofrecen recomendaciones acerca de los escenarios más rentables, considerando los actuales precios de comercialización de electricidad en el entorno de 56.53 US$/MWh y los precios del mercado de etanol: 0.30 y 0.17 US$/L.
USE OF THE LIFE CYCLE ASSESSMENT (LCA) FOR COMPARISON OF THE ENVIRONMENTAL PERFORMANCE OF FOUR ALTERNATIVES FOR THE TREATMENT AND DISPOSAL OF BIOETHANOL STILLAGE

By

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KEYWORDS: Vinasse, LCA, Fertigation, Biodigestion, Concentration, Combustion.

Abstract

New alternative routes for the treatment and disposal of stillage should be proposed, as fertigation could become unfeasible, due to the increasing transport costs and environmental concerns. The aim of this paper is to show the results of the application of the Life Cycle Assessment methodology for the analysis and comparison of four alternatives for stillage treatment and disposal: conventional ‘in natura’ fertigation, anaerobic digestion, concentration until 40% for fertigation and concentration until 65% for combustion in boilers using fuel oil as supplementary fuel. For the LCA study, a hypothetic Standard Sugar and Alcohol Mill was assumed with a milling capacity of 1.99 million tonnes of sugarcane per crop, producing 154 thousand tonnes of sugar and 81 thousand m³ of ethanol. The mill is located near the city of Sertãozinho and local soil characteristics were also considered. The environmental evaluation results comparing the 4 alternatives of disposal are shown. The Simapro® software and the CML 2 baseline 2000 are used as support tools.

Conventional and concentrated stillage fertigation alternatives have the best environmental performance. In the combustion of stillage, we considered the installation of pollution control devices for SOx and NOx with 95% efficiency. From the point of view of climate change, based on the life cycle greenhouse gases balance, the best alternative was biodigestion.

Introduction

Stillage, the most important by-product of sugarcane bioethanol production, is the aqueous by-product from the distillation of bioethanol. On an average, 8–15 litres of stillage is generated for every litre of alcohol produced.

The pollution load of the distillery effluent depends on different aspects related to the

Nomenclature

1,4-DB eq. 1,4 Dichlorobenzene equivalents
ACP Acidification Potential
ADP Abiotic Depletion Potential
CIP Clean In Place
ER Relationship between renewable energy output and fossil fuel energy input
ETP Eutrophication Potential
FEP Fresh Water Aquatic Ecotoxicity Potential
FU Functional Unit
GHG Greenhouse Gases
GWP Global Warming Potential
HTP Human Toxicity Potential
ISO International Standard Organisation
LCA Life Cycle Assessment
LCI Life Cycle Inventory
LCIA Life Cycle Impact Assessment
MEP Marine Aquatic Ecotoxicity Potential
ODP Ozone Layer Depletion Potential
POP Photochemical Oxidation Potential
SB System Boundaries
SSAM Standard Sugar and Alcohol Mill
TEP Terrestrial Ecotoxicity Potential
feedstock and process (Parnaudeau et al., 2008). Stillage might be handled several ways: discharge to an adjacent waterway or land area, return to agricultural fields (fertigation), anaerobic digestion and methane production, incineration, evaporation to an animal feed or use as an aquaculture feed (Willington and Marten, 1982; Wilkie et al., 2000; Pant and Adholeya, 2007; Mohana et al., 2009).

There has been a substantial development of life cycle methodologies to assess the energetic and environmental performance of product systems from cradle-to-grave, namely LCA (Malça and Freire, 2006).

The ISO, a worldwide federation of national standards bodies, has standardised this framework within the ISO 14040 series on LCA (ISO, 1997; 1998; 1999 and 2000).

Preliminary attempts of LCA application for the evaluation and comparison among alternatives of stillage treatment were accomplished by Rocha et al. (2007) and Rocha et al. (2008).

The objective of this work is to accomplish a comparative environmental analysis between the different scenarios corresponding to different stillage treatment and disposal alternatives.

**LCA methodology for this study**

**Definition of the goal and scope**

The function of the systems of products analysed in this work relative to different alternatives for stillage treatment:

- FCDCC: conventional fertigation with *in natura* stillage distribution through concrete channels and dispersal on farms through diesel-fuelled motor-pumps.
- ABDCC: stillage anaerobic biodigestion, with the biogas used for electric power generation and the subsequent disposition of the resulting effluent on farms.
- SCDTT: stillage concentration by evaporation up to 40% of solids, distribution on farms through trucks.
- SCCBA: stillage concentration by evaporation up to 65% of solids, to allow incineration in a boiler, together with an auxiliary fuel for steam and electric power generation. The ashes can be used for supplementary fertilisation.

**Definition of the FU and SB**

The FU is 1 m³ of stillage treated/disposal. In the agricultural system, the sum of the fertigated area with application of ashes and/or the area fertilised with mineral fertilisers will be the same for the four scenarios, but the magnitude changes (Table 1).

The operations of soil preparation, herbicide application, pesticide and limestone, harvest and transport won't be considered because they are the same for all scenarios.

The capital infrastructure contributes on average less than 5% of the global impact in all the impact categories (Rocha, 2009). So the build-up stage of the systems of stillage will not be considered in this study.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Considered items</th>
</tr>
</thead>
<tbody>
<tr>
<td>FU</td>
<td>1 m³ of treated stillage</td>
</tr>
<tr>
<td>Reference flow</td>
<td>83.3 litres of ethanol</td>
</tr>
<tr>
<td>Sugarcane corresponding to the FU</td>
<td>1.67 tonnes of sugarcane</td>
</tr>
<tr>
<td>Fertigated and non-fertigated areas total</td>
<td>0.0192 ha</td>
</tr>
<tr>
<td>Allocation method</td>
<td>Mass or energy</td>
</tr>
<tr>
<td>Impacts evaluation methodology</td>
<td>CML 2 baseline version 2.03</td>
</tr>
<tr>
<td>Data requirements</td>
<td>Data obtained from literature</td>
</tr>
</tbody>
</table>
A SSAM in the municipal district of Sertãozinho, State of São Paulo, Brazil, was established, hypothetically (Figure 1). The total period of operation will be 20 years, with 210 days of crop a year (4440 useful hours of operation). The milling capacity is of 1.99 Mt of sugarcane per crop, producing 0.154 Mt of sugar and 81,000 m³ of ethanol.

The predominant soil in the region is of the type Rhodic Hapludox and Typic Hapludox, with an average composition of 33.8% silt and 52.9% of clay (Alves, 2002).

Table 2 shows the main parameters adopted in process simulation. It is considered that 12.0 litres of stillage per litre of ethanol will be produced with the composition shown in Table 3 (Elia Neto and Nakahodo, 1995).

The main agricultural parameters considered for energy and emission analyses are presented in Table 4. The diesel consumption in the equipment used during conventional fertilisation, fertigation with ‘in natura’ and concentrated stillage and fertilisation with ashes was calculated starting from indicators presented by Macedo et al., 2004. It is considered that the cycle of the sugarcane consists of the plant cane and four ratoon crops with an average productivity of 87 tc/ha.

### Table 2—Parameters adopted for the process simulation.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific sugar production</td>
<td>80.0</td>
<td>kg/sugar/tc</td>
<td>UNICA (2008)</td>
</tr>
<tr>
<td>Specific ethanol production</td>
<td>50.0</td>
<td>l/ethanol/tc</td>
<td>UNICA (2008)</td>
</tr>
<tr>
<td>Bagasse production</td>
<td>260.0</td>
<td>kg/bagasse/tc</td>
<td>Ometto (2005)</td>
</tr>
<tr>
<td>Mechanical power demand of cane preparation and juice</td>
<td>16.0</td>
<td>kWh/tc</td>
<td>BNDES and CGEE (2008)</td>
</tr>
<tr>
<td>extraction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric power demand of sugar and ethanol process</td>
<td>12.0</td>
<td>kWh/tc</td>
<td>BNDES and CGEE (2008)</td>
</tr>
<tr>
<td>Specific steam consumption</td>
<td>540.0</td>
<td>kg/steam/tc</td>
<td>BNDES and CGEE (2008)</td>
</tr>
</tbody>
</table>
In this work, it is assumed that the stillage is applied in the plant and ratoon cane with nitrogen (48 kg/ha) and phosphorus (125 kg/ha) complementation in the plant cane (Penatti, 2008, Pers. Comm.). The emissions originating from the mineral fertilisation were calculated by the indicators shown in Table 5.

**Table 3**—Physic-chemical parameters of stillage (Elia Neto and Nakahodo, 1995).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>BOD</th>
<th>COD</th>
<th>N</th>
<th>P_2O_5</th>
<th>K_2O</th>
<th>CaO</th>
<th>MgO</th>
<th>MnO</th>
<th>Fe_2O_3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Units</td>
<td>mg/l</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Value</td>
<td>16 949</td>
<td>28 450</td>
<td>356</td>
<td>60</td>
<td>2034</td>
<td>515</td>
<td>225</td>
<td>5</td>
<td>25</td>
</tr>
</tbody>
</table>

**Table 4**—Basic data for sugarcane production, harvesting and transportation (Macedo et al., 2008).

<table>
<thead>
<tr>
<th>Item</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sucrose</td>
<td>% cane stalks</td>
<td>14.22</td>
</tr>
<tr>
<td>Fiber</td>
<td>% cane stalks</td>
<td>12.73</td>
</tr>
<tr>
<td>Trash (dry basis)</td>
<td>% cane stalks</td>
<td>14.00</td>
</tr>
<tr>
<td>Cane productivity</td>
<td>tc/ha</td>
<td>87.0</td>
</tr>
<tr>
<td>Fertiliser utilisation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P_2O_5</td>
<td>Plant cane</td>
<td>kg/ha</td>
</tr>
<tr>
<td></td>
<td>Ratoon cane without stillage</td>
<td>kg/ha</td>
</tr>
<tr>
<td>K_2O</td>
<td>Plant cane</td>
<td>kg/ha</td>
</tr>
<tr>
<td></td>
<td>Ratoon cane without stillage</td>
<td>kg/ha</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>Plant cane</td>
<td>kg/ha</td>
</tr>
<tr>
<td></td>
<td>Ratoon cane with stillage</td>
<td>kg/ha</td>
</tr>
<tr>
<td></td>
<td>Ratoon cane without stillage</td>
<td>kg/ha</td>
</tr>
</tbody>
</table>

**Table 5**—Factors for emissions resulting from mineral fertilisation.

<table>
<thead>
<tr>
<th>Released substances</th>
<th>Quantity</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission to the air resulting from nitrogen fertilisation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO_2</td>
<td>3.64 kg CO_2/kg N</td>
<td>IPCC (2006)</td>
</tr>
<tr>
<td>N_2O</td>
<td>0.05 kg N_2O/kg N</td>
<td>Crutzen et al. (2008)</td>
</tr>
<tr>
<td>NO_x</td>
<td>0.053 kg NO_x/kg N</td>
<td>Renouf et al. (2008)</td>
</tr>
<tr>
<td>NH_3</td>
<td>0.026 kg NH_3/kg N</td>
<td>Renouf et al. (2008)</td>
</tr>
<tr>
<td>Emissions to underground water (lixiviation)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO_3</td>
<td>0.065 kg NO_3/kg N</td>
<td>Renouf et al. (2008)</td>
</tr>
<tr>
<td>PO_4^3^-</td>
<td>0.128 kg P/kg P_2O_5</td>
<td>Bloesch et al. (1997)</td>
</tr>
<tr>
<td>K^+</td>
<td>0.01 kg K^+/kg K_2O</td>
<td>Paul et al. (1998)</td>
</tr>
</tbody>
</table>

**Description of evaluated scenarios**

**Scenario I: FCDC – Conventional fertirrigation**

The stillage application rate during fertirrigation is 183 m³/ha, calculated according to CETESB (2005). The scenario I scheme is shown in Figure 2.

The mass and energy balances were calculated using the software GateCycle® (Figure 3). The steam parameters considered were 6.5 MPa and 480°C.
Fig. 2—Scheme of the FCDCC scenario.
Information about environmental impacts to atmosphere from stillage application to soil is practically nonexistent; only CO₂ emissions were considered according to Almeida (1983).

**Scenario II: ABDCC – Stillage biodigestion**

The bio-digestion plant is composed of four internal circulation anaerobic reactors.

The generated biogas will be used in internal combustion engines for electricity generation, the resulting effluent of the bio-digestion process will be applied on farms through waterproof concrete channels and the dispersal will be accomplished by diesel motor-pumps (Figure 4).

The rate of application of the bio-digested stillage in the agricultural soil is 266 m³/ha.

It is considered that the biogas has the following composition: 60% CH₄, 39% CO₂ and 1% H₂S. The PCI and PCS of the biogas are 18.20 MJ/kg and 20.19 MJ/kg respectively, the specific mass is 1.10 kg/m³ and the mass flow 0.593 kg/s.

The total electric power consumed by the bio-digestion system is 539.0 kW and, for FU, the consumption will be 2.46 kWh.

The sizing of the power generation system was accomplished using the software Thermoflex®, and consisted of 2 motor-generators Jenbacher®, each one with a nominal power of 2.56 MW and global efficiency of 40.0% and 1 group motor-generator Wartsila® with a nominal power of 1.35 MW and efficiency of 31.0%; in that way, the groups will generate 16.82 kWh/m³ of stillage.
Scenario III: SCDTT – Stillage concentration and fertirrigation

In this scenario, the stillage is concentrated by evaporation up to 40.0% solids. The design of the plant was accomplished using the software Aspen Plus® (Moura, 2008, Pers. Comm.).

In the scheme, 5 evaporation effects were considered also a condenser and a CIP system.

Figure 5 displays the outline of the cogeneration plant for this case. The efficiency of the cycle was 19.0%, therefore 173.29 kWh/m³ of stillage are generated. In the whole plant, 2430 kW are consumed; therefore, to the FU, it corresponds to 11.11 kWh.

Surplus electricity is 142.14 kWh. The allocation of the atmospheric emissions will be based on the share of generated/consumed electricity in the following way: 11.6% for the process, 6.4% for the stillage concentration plant and 82.0% for surplus electricity.

The rate of application of concentrated stillage will be 9.25 m³/ha. The fertirrigated and non-fertirrigated areas for the FU will be 0.0081 e and 0.0111 hectares, respectively (Figure 6).

Scenario IV: SCCBA – Stillage concentration and incineration

The stillage is concentrated up to 65% to enable the combustion of the stillage in boilers. The design of the plant was accomplished using the software Aspen Plus® (Moura, 2008, Pers. Commun.). The ashes that result from the combustion can be used in partial substitution of the mineral fertilisers. The concentration plant will have a scheme equivalent to the one in the previous scenario; however, it should have an additional evaporation effect, having in total 6 effects (Figure 7).
Fig. 5—Cogeneration plant modeling results for SCDTT scenario.

Fig. 6—Stillage concentration plant modeling results for SCDTT scenario.
Fig. 7—Scheme of the SCCBA scenario.
Results

Inventory of the consolidated life cycle

The methodology and indicators used in the LCI in this work are described in detail in Rocha (2009). Three evaluation categories were used for the evaluation of the environmental loads in LCI: energy evaluation (output/input energy relationship), GHG emissions balance in relation to the surplus electricity exported for the public grid, and characterisation/normalisation of the environmental impacts in agreement with a specific Eco-Indicator (CML 2 baseline 2000 version 2.03).

Electricity exported as a function of the emission of CO₂ equivalent

For the four appraised alternatives, the value of the electricity exported to the net was determined, and the emissions of GHG released during the system operation (emissions of the mineral fertiliser, cogeneration, use of diesel oil, decomposition of the stillage, etc.), based on the characterisation model developed by IPCC (2006).

The characterisation factors are expressed using the global warming for a horizon of 100 years (GWP100), in kg of CO₂ equivalent/kg of emitted substance.

The substances considered in this study were CO₂ (1.0 kg CO₂ eq./kg), CH₄ (23.0 kg CO₂ eq./kg), CO (1.53 kg CO₂ eq./kg) and N₂O (296 kg CO₂ eq./kg). The results are shown in Figure 8.

Fig. 8—Rate of emission of CO₂ in function of the electricity exported for the public net.

The smallest emissions of GHG per kWh of generated electricity correspond to the scenario ABDCC (1.92 kg CO₂ eq./kWh), followed by FCDCC (2.13 kg CO₂ eq./kWh), SCCBA (2.16 kg CO₂ eq./kWh) and SCDTT (2.28 kg CO₂ eq./kWh).

Evaluation of the energy flows (Output/Input relationship) of the scenarios of disposition of the stillage

In the specific case of this study, the ER relation will indicate which scenario contributes to the largest global energy recovery from stillage before the final disposition in the soil.

The amount of necessary ethanol to assist the functional unit (83.3 litres) and the electricity exported to the net were considered as exits of the system. The outlet will be formed by the sum of the input amounts multiplied by the respective energy coefficient (Figures 9–12 and Table 6).
Fig. 9—Energy inputs and outputs considered for the evaluated scenarios for FCDCC.

Fig. 10—Energy inputs and outputs considered for the evaluated scenarios for ABDCC.

Fig. 11—Energy inputs and outputs considered for the evaluated scenarios for SCDTT.

Fig. 12—Energy inputs and outputs considered for the evaluated scenarios for SCCBA.
Table 6—Energy balance for evaluated stillage disposal and treatment scenarios.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Renewable energy output (MJ/m³ stillage)</th>
<th>Fossil fuel energy input (MJ/m³ stillage)</th>
<th>ER</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCDCC</td>
<td>118.45</td>
<td>2477.36</td>
<td>20.9</td>
</tr>
<tr>
<td>ABDCC</td>
<td>133.17</td>
<td>2538.56</td>
<td>19.1</td>
</tr>
<tr>
<td>SCDTT</td>
<td>152.56</td>
<td>2372.96</td>
<td>15.6</td>
</tr>
<tr>
<td>SCCBA</td>
<td>544.16</td>
<td>2564.36</td>
<td>4.7</td>
</tr>
</tbody>
</table>

The alternative with the best energy performance was FCDCC (20.9), followed by ABDCC (19.1) and SCDTT (15.6). The SCCBA alternative presented an energy balance of 4.7 which is lower than that reported in the literature for the whole production cycle of ethanol (Macedo et al., 2004). That is due to the use of fuel oil (9.66 kg fuel oil/m³ stillage) as auxiliary fuel for stillage combustion.

Characterisation and normalisation of the environmental impacts

In this stage, the potential effects caused by the environmental loads emitted in the product system are described in terms of consumption of natural resources, or in impacts caused to the ecosystem and human health, depending on the type of model used (midpoint or endpoint indicator).

The LCIA of the four treatment alternatives and disposition of the analysed stillage were accomplished through the use of the method CML 2 baseline 2000, with the help of the computational tool Simapro 7.0®.

Figure 13 displays a summary of the values of these categories for the disposition alternatives and treatment of the analysed stillage in percentile. Figure 14 presents a percentile comparison of the contribution of each evaluated scenario in each impact category.

In relation to the characterisation of the impacts (Figure 13), the SCDTT scenario obtained the best environmental behaviour in 5 categories, FCDCC scenario was better in 2 categories, ABDCC scenario was better in 1 category and SCCBA was better in 1 category (Table 7).
In relation to the normalisation of the impacts (Figure 14), the CML 2 baseline 2000 considers the emissions of the equivalent substances for the year of 1990. The normalisation factors are: ADP (6.32*10^{-12} kg Sb eq./year), GWP (2.27*10^{-14} kg CO2 eq./year), HTP (1.67*10^{-14} kg 1,4-DB eq./year), FEP (4.83*10^{-15} kg 1,4-DB eq./year), MEP (1.32*10^{-15} kg 1,4-DB eq./year), TEP (3.79*10^{-12} kg 1,4-DB eq./year), POP (9.59*10^{-12} kg C2H4 eq./year), ACP (3.09*10^{-12} kg SO2 eq./year) and ETP (7.53*10^{-12} kg eq./year). Therefore, in the global sum of all the categories, dimensionless the option of SCDTT obtained the best environmental performance (−1.14*10^{-11}), followed by FCDCC (−1.01*10^{-11}), ABDCC (−9.47*10^{-12}) and SCCBA (−7.58*10^{-12}).

Table 7—Characterisation of the environmental impacts of the considered scenarios.

<table>
<thead>
<tr>
<th>Impacts categories</th>
<th>Unit</th>
<th>FCDC</th>
<th>ABDCC</th>
<th>SCDTT</th>
<th>SCCBA</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADP</td>
<td>kg Sb eq.</td>
<td>−0.0455</td>
<td>−0.0551</td>
<td>−0.0171</td>
<td>0.1430</td>
</tr>
<tr>
<td>GWP</td>
<td>kg CO2 eq.</td>
<td>−698.0</td>
<td>−703.0</td>
<td>−749.0</td>
<td>−648.0</td>
</tr>
<tr>
<td>ODP</td>
<td>kg CFC-11 eq.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>HTP</td>
<td>kg 1,4-DB eq.</td>
<td>66.9</td>
<td>66.9</td>
<td>61.3</td>
<td>66.7</td>
</tr>
<tr>
<td>FEP</td>
<td>kg 1,4-DB eq.</td>
<td>0.0203</td>
<td>0.0204</td>
<td>0.0185</td>
<td>0.0234</td>
</tr>
<tr>
<td>MEP</td>
<td>kg 1,4-DB eq.</td>
<td>36.0</td>
<td>38.1</td>
<td>33.1</td>
<td>43.2</td>
</tr>
<tr>
<td>TEP</td>
<td>kg 1,4-DB eq.</td>
<td>0.00031</td>
<td>0.00523</td>
<td>0.00027</td>
<td>0.00373</td>
</tr>
<tr>
<td>POP</td>
<td>kg C2H2</td>
<td>−0.00419</td>
<td>0.00337</td>
<td>−0.00264</td>
<td>0.00283</td>
</tr>
<tr>
<td>ACP</td>
<td>kg SO2 eq.</td>
<td>0.0103</td>
<td>0.1950</td>
<td>0.0556</td>
<td>0.1670</td>
</tr>
<tr>
<td>ETP</td>
<td>kg PO4^3 eq.</td>
<td>0.6430</td>
<td>0.6700</td>
<td>0.5970</td>
<td>0.5940</td>
</tr>
</tbody>
</table>

Conclusions

The recovery of the energy value of the stillage could be accomplished before its final disposition. In this scenario, the anaerobic bio-digestion was shown to be quite favourable in three indicators: use of the soil, emission of GHG as a function of the generated kWh, and also in the use of abiotic resources. The energy recovery through combustion was shown to be environmentally
unfavourable due to the intensive use of auxiliary fuel (fuel oil), which turned it into an unfavourable scenario from the energy point of view.

The application of LCA for evaluation of the environmental impacts caused by the stillage does not allow a complete analysis, because associated uncertainties exist about the lixiviation and volatilisation of the stillage applied to the soil. Besides, ions in the stillage, mainly potassium, phosphorus (phosphate) and the nitrogen compounds can be lixiviated for the water table. The great obstacle in relation to the quantification of these impacts is the nonexistence of reliable information on what really happens with the stillage when it is applied to the soil.

Acknowledgement

The authors proudly recognise the financial support provided by Brazilian science funding agencies CAPES, CNPq and FAPEMIG

REFERENCES


LE RECOURS A L'EVALUATION DU CYCLE DE VIE (ECV) POUR LA COMPARAISON DE LA PERFORMANCE ENVIRONNEMENTALE DE QUATRE APPROCHES ALTERNATIVES POUR LE TRAITEMENT ET ELIMINATION DE LA VINASSE PROVENANT DE LA PRODUCTION D’ETHANOL

Par

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MOTS-CLÉS: Vinazes, Élimination Finale, Cycle de Vie Analyse.

Résumé

DES NOUVEAUX itinéraires alternatifs pour le traitement et l'élimination de la vinasse doivent être proposés, car la fertigation pourrait devenir non acceptable, en raison de l'augmentation des frais de transport et des préoccupations environnementales. Le but de cette communication est de démontrer les résultats de l'application de la méthodologie d'évaluation du cycle de vie (ECV) pour l'analyse et la comparaison de quatre approches de traitement et d'élimination de la vinasse: fertigation conventionnelle ‘in natura’, digestion anaérobie, concentration jusqu'à 40% pour la fertigation et concentration jusqu'à 65% pour la combustion dans les chaudières utilisant du fioul comme carburant. Pour l'étude ECV, un complexe industriel standard hypothétique de sucre et d'éthanol avec une capacité d’usinage de 1.99 millions de tonnes de canne à sucre par campagne, produisant 154 000 tonnes de sucre et de 81 000 m³ d'éthanol, a été considéré. Le complexe est situé à proximité de la ville de Sertãozinho et les caractéristiques du sol ont été prises en compte également. Les résultats de l'évaluation environnementale en comparant les quatre approches pour l'élimination de la vinasse sont détaillés. Le logiciel Simapro® et le CML2 baseline 2000 ont été utilisés comme outils de support. L'élimination de la vinasse par fertigation par mode conventionnelle et par concentration se sont avérées les meilleures approches sur le plan environnemental. Dans la combustion de la vinasse, nous avons pris en considération l'installation de dispositifs antipollution pour SOx et NOx à une efficacité de 95%. Du point de vue du changement climatique, basé sur l’équilibre du cycle de vie des gaz à effet de serre, la meilleure alternative était la biodigestion.
EMPLEO DE LA EVALUACIÓN DEL CICLO DE VIDA (LCA) PARA LA COMPARACIÓN DEL COMPORTAMIENTO AMBIENTAL DE CUATRO ALTERNATIVAS PARA EL TRATAMIENTO Y DISPOSICIÓN DE LAS VINAZAS RESIDUALES DEL ETANOL

Por

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PALABRAS CLAVES: Vinazas, Disposición Final, Análisis del Ciclo de Vida.

Resumen

Es conveniente proponer nuevas rutas para el tratamiento y disposición de las vinazas residuales de la producción de etanol en cuanto la fertirrigación puede resultar inviable debido a los incrementos de los costos de transporte y preocupaciones ambientales. El objetivo de este trabajo es mostrar los resultados de la aplicación de la metodología de Evaluación del Ciclo de Vida (LCA, en inglés) para el análisis y la comparación de cuatro (4) alternativas para el tratamiento y la disposición de las vinazas residuales: convencional con fertirrigación ‘al natural’, digestión anaeróbica, concentración hasta el 40% (de sólidos) para fertirrigación y concentración a 60% para combustión en calderas empleando fuel oil como combustible complementario. Para el estudio del LCA, se asumió un hipotético Central Productor de Azúcar y Alcohol (SSAM), con una capacidad de molienda de 1.99 millones de toneladas de caña por zafra, produciendo 154 mil toneladas de azúcar y 81 mil m³ de etanol. El central está localizado cerca de la ciudad de Sertaozinho y se consideraron las condiciones de los suelos locales. Se presentan los resultados de la evaluación ambiental al comparar las cuatro alternativas de disposición. Se emplearon como herramientas de soporte digital el software SIMAPRO® y la baseline CML 2, 2000. Las alternativas de fertirrigación convencional y la de concentración tuvieron en general el mejor desempeño ambiental. En la combustión de las vinazas consideramos la instalación de componentes de control de la contaminación, con 95% de eficiencia para SOx y NOx. Desde el punto de vista del Cambio Climático, basado en el balance del Ciclo de Vida de Gases de Efecto Invernadero, la mejor alternativa resultó la biodigestión.
EFFECT OF CALCIUM IONS ON ETHANOL PRODUCTION FROM MOLASSES BY SACCHAROMYCES CEREVISIAE

By

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KEYWORDS: Molasses, Ethanol, Calcium, Saccharomyces cerevisiae, Invertase.

Abstract

ONE OF THE most widely used feedstocks for potable or biofuel ethanol fermentation is blackstrap molasses, a by-product of cane sugar production. Inconsistent quality of molasses frequently found in industrial production, however, makes ethanol production much less efficient and cost-ineffective. Besides fermentable sugars (sucrose, glucose and fructose) present in molasses, calcium is also found in the range of 10–20% of the total carbonated ash (15% by weight). In the sugar process, calcium is usually applied as lime, CaO, during defecation, which sometimes results in over-liming if juice quality is poor. In this study, the role of calcium residues (0–0.72% w/v of Ca²⁺ in the form of calcium chloride) on fermentation efficiency of yeast was evaluated using model solutions of sucrose, glucose and fructose (20% w/v). The results suggest a detrimental effect of calcium ions on yeast performance which was concentration dependent. A slight decrease in fermentation rates and ethanol yields was evident when calcium was present at 0.18% w/v Ca²⁺ in all sugar solutions. This effect was more pronounced when calcium ion concentration increased. At 0.72% w/v of Ca²⁺, the rates of fermentation and ethanol yields of all sugars were considerably decreased (the ethanol yields decreased by 14–25% relative to the control sample, i.e. no calcium ion added). At a very high concentration of Ca²⁺ (2.16% w/v), yeast fermentation of sucrose was almost absolutely inhibited. This might be, in part, due to the inhibition effect of invertase enzyme for conversion of sucrose to invert sugars, a limiting step in ethanol fermentation of sucrose by yeast. The pretreatment of molasses by acid and heat prior to fermentation was then introduced to remove calcium which improved the fermentation efficiency.

Introduction

The most widely used feedstock for potable or biofuel ethanol fermentation by yeast, Saccharomyces cerevisiae, is sugarcane in forms of syrup and blackstrap molasses, a by-product from cane sugar production. Molasses is rich in many nutrients that are essential for microbial fermentation. It consists mainly of sugars including sucrose, glucose and fructose (approximately 30–40, 4–9 and 5–12 g/100g molasses, respectively) (Chen and Chou, 1993).

Sucrose, the most available fermentable sugar in molasses, is first inverted by yeast-secreted invertase sugars which are subsequently converted, under anaerobic conditions, by yeast to ethanol and carbon dioxide.
Besides these fermentable sugars, there are other components, viz. protein, minerals (potassium, calcium, sodium, magnesium, copper, iron, manganese, zinc, chloride and sulfur) and vitamins (biotin, folic acid, riboflavin, thiamine and niacin) some of which are essential for yeast growth and metabolism.

Among various minerals present in molasses, calcium is found as the second after potassium, in the range of 0.3–0.9 and 1.5–6.0% by weight of molasses with 75% dry substance for calcium and potassium, respectively (Higginbotham and McCarthy, 1998). In the sugar process, calcium is typically applied as lime, CaO, during defecation, which sometimes results in over-liming if juice quality is poor. Calcium can be discharged into the final molasses which presumably affects the ethanol production efficacy in various process stages, including yeast fermentation and ethanol distillation.

In this study, the role of calcium residues (0–0.72% w/v of Ca$^{2+}$ in the form of calcium chloride) on fermentation efficiency of yeast was evaluated using model solutions of sucrose, glucose and fructose (20% w/v).

**Materials and methods**

**Materials**

Molasses was obtained from MitrPhol sugar factory, Thailand. An invertase enzyme ($\beta$-fructofuranosidase) was supplied by Novozymes Co. Ltd. (Bagsvaerd, Denmark). Yeasts, *Saccharomyces cerevisiae*, were a commercial dry active product (BioFerm-XR, North American Bioproducts Corporation - NABC, USA).

**Effect of calcium on yeast fermentation of sucrose at high calcium concentrations (0–2.16% w/v of Ca$^{2+}$)**

The sucrose solution (20% w/v) containing different calcium concentrations (0–2.16% w/v of Ca$^{2+}$ in the form of CaCl$_2$.2H$_2$O) was prepared with the addition of some nutrients (10 g/L of yeast extract; 1 g/L of KH$_2$PO$_4$; 1g/L of (NH$_4$)$_2$SO$_4$ and 0.5 g/L of MgSO$_4$.7H$_2$O) at pH 4.5. Yeasts, *Saccharomyces cerevisiae* (BioFerm-XR) were added (0.6 g/L) and the fermentation was achieved at 32°C for 48 h in a 5L-fermentor with controlled temperature and pH. The samples were collected at different time intervals and analysed for sugar and ethanol contents by High Performance Liquid Chromatography methods using a Sugar-Pak TMI column (6.5 x 300 mm; Waters Corporation, MS, USA) at 80°C with a Refractive Index detector (Water 410 Differential Refractometer, Waters Corporation, MS, USA) and the eluent of 0.05 g/L Calcium Titriplex® dihydrate at the flow rate of 0.5 mL/min, according to ICUMSA Method GS7-23 (ICUMSA, 1994). The fermentation efficiencies were reported as a percentage of experimental to theoretical yields of ethanol.

**Effect of calcium on yeast fermentation of sucrose, glucose and fructose at low calcium concentrations (0–0.72% w/v of Ca$^{2+}$)**

The sugar solutions, i.e. sucrose, glucose and fructose (20% w/v) containing different calcium concentrations (0, 0.18, 0.36 and 0.72% w/v of Ca$^{2+}$ using 0, 0.5, 1.0 and 2.0% w/v of CaCl$_2$.2H$_2$O, respectively) were prepared with the addition of some nutrients (10 g/L of yeast extract; 1 g/L of KH$_2$PO$_4$; 1 g/L of (NH$_4$)$_2$SO$_4$ and 0.5 g/L of MgSO$_4$.7H$_2$O) at pH 4.5. Yeasts, *Saccharomyces cerevisiae* (BioFerm-XR) were added (0.6 g/L) and the fermentation was achieved at 32°C for 48 h in a 1 L-flask without controlled temperature and pH.

The samples were collected at different time intervals and analysed for sugar and ethanol contents by High Performance Liquid Chromatography methods using a Sugar-Pak TMI column (6.5 x 300 mm; Waters Corporation, MS, USA) at 80°C with a Refractive Index detector (Water 410 Differential Refractometer, Waters Corporation, MS, USA) and the eluent of 0.05 g/L Calcium Titriplex® dihydrate at the flow rate of 0.5 mL/min, according to ICUMSA Method GS7-23 (ICUMSA, 1994). The fermentation efficiencies were reported as a percentage of experimental to theoretical yields of ethanol.
Effect of calcium concentration on hydrolytic activity of invertase enzymes

The sucrose solutions (10% w/v) containing different calcium concentrations, i.e. 0, 0.18, 0.36, 0.72, 1.44, 2.16 and 2.88% w/v (in a form of CaCl$_2$.2H$_2$O) were thoroughly mixed with invertase enzymes (the enzyme concentration was 5.84 mg/mL) at pH 4.5.

The mixtures were incubated at 32 and 55°C for 1 h. Subsequently, the enzyme activities were terminated by boiling for 15 min and the aliquots were used to quantify the amount of reducing sugars by Somogyi-Nelson method (Somogyi, 1952).

Fermentation of molasses with acid pretreatment

The qualities of molasses were analysed including total soluble solids by a refractometer, sulfated ash (GS1/3/4/7/8-11 method) and conductivity ash (GS1/3/4/7/8-13 method) according to ICUMSA method (ICUMSA, 1994) and pH by a pH meter.

The amount of fermentable sugars was quantified using a High Performance Liquid Chromatography (ICUMSA Method GS7-23; ICUMSA, 1994) equipped with a Sugar-Pak TMI column (6.5 × 300 mL, Water Corporation, MS, USA) at 80°C and operated with 0.05 g/L calcium titriplex® dehydrate (Ca-EDTA) at the flow rate of 0.5 mL/min. The calcium content was estimated by Inductively Coupled Plasma technique (AOAC, 2000).

Molasses was pretreated with sulfuric acid prior to yeast fermentation. Sulfuric acid (1N H$_2$SO$_4$) was added to molasses until the pH of sample reached 3.0. The mixture was then heated to 95°C for 0.5 h and then left overnight at room temperature.

The precipitates were then removed by filtration. The pretreated molasses was subsequently fermented by adjusting the total soluble solid content of molasses to 25°Brix at pH 4.5. Some essential nutrients including 10 g/L of yeast extract; 1 g/L of KH$_2$PO$_4$; 1 g/L of (NH$_4$)$_2$SO$_4$ and 0.5 g/L of MgSO$_4$.7H$_2$O were added to ensure a proper growth of yeast during ethanol fermentation.

The fermentation was achieved by *Saccharomyces cerevisiae*, without and with 0.36% calcium (or 1% w/v of calcium chloride, CaCl$_2$.2H$_2$O), at 32°C for 48 h.

The samples were collected at different time intervals and analysed for sugar and ethanol contents by chromatographic methods as described previously.

Results and discussion

Sucrose, a major sugar component found in cane molasses, is a fermentable sugar that can be converted to ethanol by yeast fermentation. During fermentation, yeasts convert sucrose to invert sugars by invertase enzymes secreted by yeasts themselves.

In this study, ethanol was produced from sucrose solutions containing different calcium concentrations (0–2.16 % Ca$^{2+}$). Figure 1 demonstrates the effect of calcium ions on the ethanol production of sucrose by yeasts.

Calcium induced a reduction in ethanol production. The adverse effect was more pronounced when the calcium concentrations increased; the ethanol yield could be reduced up to 86% (the ethanol yields and fermentation efficiencies were decreased from 0.508 to 0.070 g/g sugar as invert and from 99.38 to 13.71% for samples with 0 and 2.16% Ca$^{2+}$, respectively (Table 1).

A reduction of ethanol production during sucrose fermentation induced by calcium was likely caused by an inhibition effect of invertase by calcium.

In fact, the conversion of sucrose to invert sugars is reported as the limiting step for ethanol production by yeast fermentation of sucrose.

Takeshige and Ouchi (1995) reported the effect of some metal ions on ethanol productivity by yeasts, which were strain-dependent.

The yeast strain with low ethanol productivity exhibited a lower invertase activity when it utilised molasses containing metal ions, in particular copper, potassium and calcium, indicating an inhibition effect on invertase activity.
Fig. 1—Changes of ethanol and sucrose concentrations during fermentation of sucrose (20% w/v) having different calcium concentrations (0–2.16% w/v of Ca\(^{2+}\)) by *Saccharomyces cerevisiae*. (Open symbols represent sugar contents and filled symbols represent ethanol content at different calcium concentrations; ○, ● 0%; △, ▲ 0.72%; □, ■ 1.44% and ◊, ♦ 2.16% Ca\(^{2+}\)).

Table 1—Yield (g /g initial sugar as invert) and % fermentation efficiency of ethanol production from sucrose solutions (20% w/v) containing different calcium concentrations.

<table>
<thead>
<tr>
<th>Calcium concentrations (% w/v)</th>
<th>Initial sugar concentrations, as inverts (% w/v)</th>
<th>Ethanol concentrations (% w/v)</th>
<th>Yield (g/g initial sugar as invert)</th>
<th>% Fermentation efficiency(a)</th>
<th>% Reduction(b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>20.46</td>
<td>10.39</td>
<td>0.508</td>
<td>99.38</td>
<td>–</td>
</tr>
<tr>
<td>0.72</td>
<td>20.79</td>
<td>7.37</td>
<td>0.354</td>
<td>69.37</td>
<td>30.22</td>
</tr>
<tr>
<td>1.44</td>
<td>20.73</td>
<td>3.66</td>
<td>0.177</td>
<td>34.55</td>
<td>65.24</td>
</tr>
<tr>
<td>2.16</td>
<td>20.12</td>
<td>1.41</td>
<td>0.070</td>
<td>13.71</td>
<td>86.20</td>
</tr>
</tbody>
</table>

(a) reported as a percentage of experimental to theoretical yields of ethanol
(b) reported as the percentage of the difference between the control experiment (without calcium) and the treatment (with calcium) to the control experiment.

\[
\text{% Reduction} = \frac{(\text{Ethanol yield}_{\text{control}}) - (\text{Ethanol yield}_{\text{treatment}})}{(\text{Ethanol yield}_{\text{control}})} \times 100
\]

To further investigate that, sucrose solutions were converted to invert sugars by external invertase in the presence of calcium. Regardless of the incubation temperatures at 55°C, an optimum temperature of this enzyme or 32°C, an optimum temperature for *Saccharomyces cerevisiae* yeast, the invertase enzymes were inhibited by calcium as the amount of reducing sugars was lower (Figure 2).

At 55°C, the effect of calcium was less as compared to that at 32°C. At a low calcium concentration (0.18% w/v), the activity reduction of invertase enzymes was 1.84 and 17.29% at 55 and 32°C, respectively, as compared to the control treatment, i.e. no calcium addition.
The effects of calcium, at low concentrations (0–0.72% w/v Ca$^{2+}$), on ethanol productivity were further investigated by fermenting sucrose, glucose and fructose with *Saccharomyces cerevisiae* yeasts at 32°C without controlled conditions to simulate the actual industrial process.

Without calcium ions, the fermentation efficiencies of all sugars were highest, yet the fermentation efficiency of sucrose was lower than the previous trial which was achieved under controlled conditions in a fermentor.

Nevertheless, the results demonstrated the reduction of ethanol productivity during fermentation of sucrose, glucose and fructose by *Saccharomyces cerevisiae* yeasts when calcium ions were added (Table 2).

The degrees of fermentation efficiency reduction were different. It was likely that fermentation of glucose was least affected by calcium.

At the same level of calcium, fermenting sucrose seemed to be the most affected by calcium (% yield reductions were 25.16, 13.72 and 20.18% for sucrose, glucose and fructose fermentation in the presence of 0.72% w/v Ca$^{2+}$, respectively.)
Table 2—Yield (g/g initial sugar as invert) and % fermentation efficiency of ethanol production from glucose and fructose solutions (20% w/v) containing different calcium concentrations.

<table>
<thead>
<tr>
<th>Sugar</th>
<th>Calcium concentrations (% w/v)</th>
<th>Initial sugar concentrations, as invert (% w/v)</th>
<th>Ethanol concentrations (% w/v)</th>
<th>Productivity g/L/h</th>
<th>Yield (g/g initial sugar as invert)</th>
<th>% Fermentation efficiency (a)</th>
<th>% Reduction (b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sucrose</td>
<td>0</td>
<td>20.26</td>
<td>8.71</td>
<td>1.81</td>
<td>0.43</td>
<td>84.11</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>0.18</td>
<td>20.26</td>
<td>8.32</td>
<td>1.73</td>
<td>0.41</td>
<td>80.35</td>
<td>4.46</td>
</tr>
<tr>
<td></td>
<td>0.36</td>
<td>20.26</td>
<td>8.11</td>
<td>1.69</td>
<td>0.40</td>
<td>78.34</td>
<td>6.86</td>
</tr>
<tr>
<td></td>
<td>0.72</td>
<td>20.26</td>
<td>6.46</td>
<td>1.35</td>
<td>0.32</td>
<td>62.44</td>
<td>25.16</td>
</tr>
<tr>
<td>Glucose</td>
<td>0</td>
<td>17.93</td>
<td>7.90</td>
<td>2.19</td>
<td>0.44</td>
<td>86.20</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>0.18</td>
<td>17.93</td>
<td>7.74</td>
<td>2.15</td>
<td>0.43</td>
<td>84.50</td>
<td>1.97</td>
</tr>
<tr>
<td></td>
<td>0.36</td>
<td>17.93</td>
<td>7.40</td>
<td>2.06</td>
<td>0.41</td>
<td>80.80</td>
<td>6.26</td>
</tr>
<tr>
<td></td>
<td>0.72</td>
<td>17.93</td>
<td>6.81</td>
<td>1.42</td>
<td>0.38</td>
<td>74.37</td>
<td>13.72</td>
</tr>
<tr>
<td>Fructose</td>
<td>0</td>
<td>19.06</td>
<td>8.15</td>
<td>2.26</td>
<td>0.43</td>
<td>83.70</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>0.18</td>
<td>19.06</td>
<td>7.79</td>
<td>1.62</td>
<td>0.41</td>
<td>81.23</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>0.36</td>
<td>19.06</td>
<td>6.94</td>
<td>1.45</td>
<td>0.36</td>
<td>71.95</td>
<td>11.16</td>
</tr>
<tr>
<td></td>
<td>0.72</td>
<td>19.06</td>
<td>6.24</td>
<td>1.30</td>
<td>0.33</td>
<td>64.00</td>
<td>20.18</td>
</tr>
</tbody>
</table>

(a) reported as a percentage of experimental to theoretical yields of ethanol
(b) reported as the percentage of the difference between the control experiment (without calcium) and the treatment (with calcium) to the control experiment.

$$\text{% Reduction} = \frac{(\text{Ethanol yield}_{\text{control}}) - (\text{Ethanol yield}_{\text{treatment}})}{(\text{Ethanol yield}_{\text{control}})} \times 100$$

The composition of molasses is presented in Table 3. Calcium can affect the production efficiency of ethanol from molasses as it acts as an inhibitor of invertase enzymes, which are very crucial for breaking sucrose to glucose and fructose.

This causes a slow reaction rate during the limiting step of molasses fermentation. In addition to the inhibition effect, the metal ion can be toxic to the yeasts and influence the ionic strength and pH of the medium.

Table 3—Qualities of molasses.

<table>
<thead>
<tr>
<th>Compositions/parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sucrose (% by weight)</td>
<td>32.60</td>
</tr>
<tr>
<td>Glucose (% by weight)</td>
<td>4.90</td>
</tr>
<tr>
<td>Fructose (% by weight)</td>
<td>7.40</td>
</tr>
<tr>
<td>Calcium (% by weight)</td>
<td>0.66</td>
</tr>
<tr>
<td>Conductivity ash (% by weight)</td>
<td>10.18</td>
</tr>
<tr>
<td>Sulfated ash (% by weight)</td>
<td>10.21</td>
</tr>
<tr>
<td>Total soluble solids (°Brix)</td>
<td>85.20</td>
</tr>
<tr>
<td>pH</td>
<td>5.16</td>
</tr>
</tbody>
</table>

Some techniques are introduced to minimise this problem such as the addition of external invertase which is not cost-effective and the formation of insoluble complexes of metal ions with some chemicals, e.g. ferrocyanide and EDTA (Oderinde et al., 1986). The pretreatment of molasses with sulfuric acid is also applied in order to remove calcium ions.

In this work, blackstrap molasses containing 0.66% w/v Ca$^{2+}$ was used for ethanol production with the acid pretreatment. As expected, a slight improvement on ethanol production from pretreated molasses was observed (Figure 3).
Conclusion

In the cane sugar process, molasses can be adulterated with calcium ions, leading to its inferior quality and for being used as the feedstock for ethanol production by yeast fermentation.

Calcium ions can act as an invertase inhibitor which inhibits the inversion of sucrose to invert sugars. Furthermore, the fermentation of invert sugars can be adversely affected by calcium.

It is, therefore, critical for ethanol factories to analyse the quality of molasses prior to use. An efficient technique for eliminating calcium should be further developed for industrial uses.

REFERENCES


EFFET DES IONS DE CALCIUM SUR LA PRODUCTION DE L'ÉTHANOL À PARTIR DE LA MÉLASSE PAR LES SACCHAROMYCES CEREVISIAE

Par

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MOTS-CLÉS: Mélasse, Éthanol, Calcium, Saccharomyces cerevisiae, Invertase.

Résumé

UN DES PRODUITS de base le plus largement utilisé pour la fermentation de l’alcool de bouche ou de biocarburant est la mélasse ‘blackstrap’, un sous-produit de la production de sucre à partir de la canne à sucre. La qualité irrégulière de la mélasse, fréquemment issue de la production industrielle, fait cependant que la production d'éthanol soit moins efficace en quantité de produit obtenu et en coût. En outre des sucres fermentescibles réducteurs (saccharose, glucose et fructose) présents dans la mélasse, le calcium se trouve également dans la plage de 10 à 20% des cendres carbonatées totales (15% en poids). Lors de la fabrication de sucre, le calcium est généralement appliqué sous forme de chaux, CaO, au cours de la défécation, ce qui entraîne parfois un chaulage en excès si la qualité de jus est mauvaise. Dans cette étude, le rôle des résidus de calcium (0–0.72% m/v de Ca2+ sous la forme de chlorure de calcium) sur l'efficacité de la fermentation par levure a été évalué à l'aide des solutions modèles de saccharose, de glucose et de fructose (20% p/v). Les résultats suggèrent un effet néfaste des ions de calcium sur les performances des levures qui étaient en relation avec la concentration. Une légère baisse de taux de fermentation et des rendements de l'éthanol étaient évidents lorsque le calcium était présent à 0.18% m/v Ca2+ dans toutes les solutions de sucre. Cet effet a été plus prononcé lorsque la concentration en ions de calcium a augmenté. À 0.72% m/v de Ca2+, les taux de fermentation et les rendements d'éthanol de tous les sucres ont été considérablement réduits (les rendements en éthanol ont diminué de 14 à 25% par rapport à l'échantillon de contrôle, c'est-à-dire aucun ion de calcium ajouté). À une très forte concentration de Ca2+ (2.16% m/v), la fermentation de saccharose par la levure a été presque totalement inhibée. Cela peut être, en partie, en raison de l'effet d'inhibition des enzymes invertases pour la conversion de saccharose en sucres invertis, une étape limitative de la fermentation de saccharose en éthanol par la levure. Le prétraitement des mélasses par acide et la chaleur avant la fermentation a été ensuite introduit pour éliminer le calcium, ce qui a amélioré l'efficacité de fermentation.
EFECTO DE LOS IONES CALCIO EN LA PRODUCCIÓN DE ETANOL A PARTIR DE MELAZAS POR SACCHAROMYCES CEREVISIAE

Por

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APARAS CLAVE: melazas, Etanol, Calcio, Saccharomyces cerevisiae, Invertasa.

Resumen

UNA DE LAS materias primas más ampliamente utilizadas para la fermentación del etanol potable y combustible son las mieles finales de caña (miele C), un subproducto de la producción de azúcar de caña. La inconsistente calidad de las mieles en la producción industrial, hacen, sin embargo, la producción de etanol mucho menos eficiente y efectiva económicamente. Además de los azúcares fermentables (sacarosa, glucosa, fructosa) presente en las melazas, también el calcio se encuentra en un rango de 10–20% de la ceniza total carbonada (15% en peso). En el proceso azucarero el calcio se aplica usualmente como lechada, CaO, durante la clarificación, lo que resulta en una sobre alcalización si la calidad del jugo es pobre. En este estudio se evalúa el papel de residuos de calcio (0–0.72% w/v de Ca²⁺ en forma de cloruro de calcio). Los resultados sugieren un efecto depresor de los iones calcio sobre el comportamiento de la levadura que era dependiente de la concentración. Resultó evidente un ligero crecimiento en la velocidad de fermentación y en el rendimiento de etanol cuando el calcio estaba presente a 0.18%w/v Ca²⁺ en todas las soluciones de azúcar. Este efecto fue más pronunciado cuando la concentración de iones calcio se elevaba. A valores de 0,72% w/v Ca²⁺, las velocidades de fermentación y los rendimientos de etanol en base a todos los azúcares caían considerablemente (el rendimiento de etanol decía 14–25% en relación con las muestras de control que no tenían calcio). A muy altas concentraciones de Ca²⁺ (2.16% w/v), la fermentación de azúcares por las levaduras fue casi absolutamente inhibida. Esto puede deberse, en parte, al efecto inhibidor de la enzima invertasa en la conversión de sacarosa en azúcares invertidos, un paso limitante en la fermentación alcohólica de los azúcares por levaduras. El pretratamiento de las melazas con ácido y calor, previa a la fermentación, se aplicó para remover el calcio, lo que mejoró la eficiencia de fermentación.
THERMAL UTILISATION OF VINASSE AS ALTERNATIVE FUEL

By

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KEYWORDS: Vinasse, Molasses, Steam Production, Swirlburner.

Abstract

SAACKE has designed a special burner for utilising biogenic fuels that occur as by-products, for example during the production of bioethanol. When the fermented mash from soy or sugarcane molasses is distilled to separate bioethanol, soy molasses and vinasse are produced. From the point of view of combustion, molasses and vinasse are very similar (40–50% water, 40–50% organics, about 10% ash). These are liquid by-products with an extremely low calorific value that could not be used to generate energy in the past. Today, the SSB-LCL swirl burner makes it possible to use these materials in concentrated form, with around 20 percent support fuel added to them, to generate heat, which is in turn fed back into the production process. As a result, 80 percent of the fuels previously required to produce bioethanol can be saved. When soy molasses and vinasse are burnt, only ash remains as a high-quality, odourless fertiliser that can be returned to the soil. This is an enormous benefit for the environment because nowadays the residue from soy and sugar production in Asia and Latin America is generally dumped on the area under cultivation. The first step in this direction has already been taken in Brazil: in Araucaria, in the State of Paraná, where molasses and vinasse have been burnt using SAACKE burners since 2007.

Introduction

Several academic works deal with efforts to achieve ‘zero effluent’ in alcohol distilleries as well as significant energy savings (Perera, 2008, Avram-Waganoff et al., 2009, Schopf and Erbino, 2006). These papers put forward irrefutable arguments demonstrating the feasibility and desirability of this goal.

One of the requirements for achieving these goals is utilisation of vinasse as a fuel, which will be explained in detail in the following.

Functional principle of the SSB-LCL burner

Low calorific fuels such as soy molasses or vinasse have calorific values that are too low to be burnt with conventional burners. However, it is possible to burn such fuels in a SSB-LCL (SAACKE Swirl Burner for Low Calorific Liquids) firing system and to feed the resulting exhaust gases to a boiler or a combustor. The system consists of a SAACKE swirl burner with a special burner throat.

The SSB is a well-proven gun-type burner for industrial and power station plants. This burner was developed for the combustion of natural gas and fuel oil and operates according to the ‘mixing at the burner mouth’ principle. This burner results in particularly low CO and NOx emissions. It is meanwhile also used in a lot of applications for low calorific gases with even below 3 MJ/m³ LHV.

The swirl-type burner primarily consists of the following structural components (Figure 1):

- Tangential wind box.
- Central fuel gun for vinasse.
• Second fuel gun for support fuel (liquid or gaseous).
• Combustion air control damper with control drive.
• Core air damper with control drive.
• Combustion air monitoring system consisting of a pressure monitor with test valve and pressure gauge with isolating valve.
• Flame scanner and gas-electric igniter.

The firing plant is started up with a high calorific fuel using the swirl burner and heated up to the temperature in the throat required for complete combustion of the gases. The typical temperature is about 650°C which is reached in about 30 minutes.

The low calorific fuel is then supplied to the burner via a dedicated atomising system. The fuel quantity required to start up the combustor is reduced for subsequent low calorific combustion so that a pilot flame is continually maintained assuring safe combustion of the low calorific fuel.

The required quantity of support fuel depends on the burning characteristics of the low calorific fuel used.

The required combustion air is tangentially supplied via the burner inlet elbow. In this inlet it is fed into the annulus between inner and outer body and accelerated in the conical part from which the swirled air then enters the furnace. The air annulus is adjusted such that an overcritical swirl is generated in the furnace. The core air is supplied to the burner separately and flows through the annulus between the fuel gun and the concentric core air tube. The combustion air and the core air control damper are adjusted by a control drive depending on the load requirements. The control drives are activated by the compound control system.

By optimum positioning of main and core air a wide control range, optimum combustion and low emission values are safely achieved at all burner loads.

The strong swirling of the combustion air causes a very intense mixing of fuel and air, which together with the hot brickwork lining provides for safe ignition of the mixture and total burn-out with a homogeneous temperature profile. Liquid as well as gaseous fuels can be used as start-up and pilot fuel. Ash fusion is avoided by controlling the flame temperature, either by means of the excess air ratio or percentage of support fuel. Therefore, all ash components are in the flue gas as dry powder.
Table 1—Fuel characteristics.

<table>
<thead>
<tr>
<th>Fuels</th>
<th>Vinasse</th>
<th>Soy molasses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic content</td>
<td>52.65%</td>
<td>51.1%</td>
</tr>
<tr>
<td>Water content</td>
<td>35%</td>
<td>41.5%</td>
</tr>
<tr>
<td>Ash</td>
<td>12.35%</td>
<td>7.4%</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.84%</td>
<td>0.14%</td>
</tr>
<tr>
<td>Carbon</td>
<td>21.87%</td>
<td>30.1%</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>3.58%</td>
<td>4.4%</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.75%</td>
<td>0.06%</td>
</tr>
<tr>
<td>Oxygen organic</td>
<td>25.6%</td>
<td>16.6%</td>
</tr>
<tr>
<td>Viscosity</td>
<td>cSt 50/100 °C ~ 80/~ 15</td>
<td>289/20</td>
</tr>
<tr>
<td>Lower heat value (LHV)</td>
<td>7.47 MJ/kg</td>
<td>10.3/11.2</td>
</tr>
</tbody>
</table>

Vinasse is a final by-product of fermentation to alcohol. After removal of the alcohol by distillation the remaining material is vinasse. For combustion it should be concentrated up to 40–50% of water.

Soy molasses is a final by-product of the soy protein industry. For combustion it should be concentrated.

Case study

Two SSB-LCL burners, each rated at 26 MW, were installed on a boiler at Araucaria in Brazil (Schopf, 2009). At about the same time, a 35 MW burner was installed on another boiler. The case study examines the boiler containing the two 26 MW burners (see Tables 2 and 3).

One of the main fuels is vinasse with either natural gas or fuel oil as support fuel. The specification for the boiler design required that maximum percentage of the support fuel must not exceed 20%. It is planned to upgrade the boiler to 42 Bar (g) and 70 t/h in the future. The burners are designed for this purpose.

Table 2—Boiler data.

<table>
<thead>
<tr>
<th>Location</th>
<th>Araucaria, State of Parana, Brazil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application</td>
<td>Water tube boiler</td>
</tr>
<tr>
<td>Type</td>
<td>Biomass design (see Figure 3)</td>
</tr>
<tr>
<td>Capacity</td>
<td>60 t/h (future 70 t/h)</td>
</tr>
<tr>
<td>Boiler heat input at MCR</td>
<td>52 000 kW</td>
</tr>
<tr>
<td>Steam pressure</td>
<td>13 bar(g) (future 42 bar(g))</td>
</tr>
<tr>
<td>Steam temperature</td>
<td>saturated steam (future 400°C)</td>
</tr>
<tr>
<td>Furnace size (width x height x length)</td>
<td>5175 x 4945 x 13 200 mm</td>
</tr>
<tr>
<td>Furnace projected heating surface</td>
<td>285 m²</td>
</tr>
<tr>
<td>Furnace volume</td>
<td>331 m³</td>
</tr>
<tr>
<td>Combustion air temperature from design</td>
<td>230°C</td>
</tr>
<tr>
<td>Burner type</td>
<td>2 x SSBS-LCL 200</td>
</tr>
<tr>
<td>Burner input</td>
<td>2 x 26 MW</td>
</tr>
<tr>
<td>Burner position</td>
<td>Horizontal, two above each other</td>
</tr>
<tr>
<td>Main fuels</td>
<td>Vinasse or soy molasses</td>
</tr>
<tr>
<td>Support/secondary fuel</td>
<td>Natural gas, oil from animal fat and soy bean husks</td>
</tr>
<tr>
<td>In operation since</td>
<td>July 2007 (Schopf, 2009)</td>
</tr>
</tbody>
</table>
Obstacles surmounted in the projects

**High ash content in soy molasses/vinasse fuels**

It was mainly a problem of the boiler design. The solution was achieved by means of an optimised flue gas system design, strategic soot blower system equipment installation and the scrubber system. Considering the high amount of ash in the fuels, we can say the results have been satisfactory. The continuous operation time of the boiler is about 3 months without shutdown. Most of the ash is removed behind the boiler by a Venturi scrubber.

**High water content in soy molasses/vinasse fuels**

It was a major point to be considered from the point of view of the boiler design because the water vapour generated in exhaust gases due to the water content of the fuel is extremely high (up to 40% by volume).

In addition, it is a major obstacle for the combustion system. Flame stability was only possible by using the special SSB-LCL combustion system. The high swirl and special LCL burner throat ensure flame stability.

**Very low heat calorific value of soy molasses/vinasse fuels**

It was a challenge especially for the combustion system. Flame stability was only possible by using the special SSB-LCL combustion system. The high swirl and the combustion chamber ensure flame stability.

**Conditioning system for proper atomisation of soy molasses/vinasse fuels**

This point requires special attention due to the corrosibility of soy molasses, the crystallisation (sugar caramel) that occurs in contact with heated surfaces and the difficulty in achieving good atomisation. The piping material and pumps used are specially designed. The heating system with a viscosity control loop involves direct steam injection. The optimum atomisation was achieved by testing several nozzle types and testing different viscosity conditions as well several molasses concentrations (see Figure 2).

![Vinasse viscosities in dependence on temperature](image)

Fig. 2—Influence of dry matter levels and preheating temperature on the viscosity of vinasse.

**Results**

The experience gained provided good feedback and knowledge for the combustion system manufacturer and the boiler manufacturer. The technology is a proven one.

The main points are that at 5% oxygen in the fuel gas (typical operation point) the CO emissions are significantly below 50 ppm and the NOx value is below 300 ppm (Table 3). Another important point is that no slagging occurs in the burner throat or the boiler, which is achieved by the burner management system (BMS) supplied by SAACKE. This is done by controlling the flame temperature in a small range between 850–950°C with the help of either excess air ratio or percentage of support fuel. By this the continuous operation time of the boiler is more than 3 months.
Last but not least: the plant in Araucaria (Figures 3, 4, 5) will pay for itself within far less than two years because 80% of the natural gas previously used is saved! The results surpassed the initial expectations.

Table 3—Emission values SSB-LCG burner, case study boiler at Araucaria.

<table>
<thead>
<tr>
<th>Description</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam flow production</td>
<td>T/h</td>
<td>70</td>
</tr>
<tr>
<td>Steam pressure (production)</td>
<td>bar(g)</td>
<td>11.6</td>
</tr>
<tr>
<td>Nat gas flow</td>
<td>Nm³/h</td>
<td>550</td>
</tr>
<tr>
<td>Soy Molasses flow</td>
<td>t/h</td>
<td>15</td>
</tr>
<tr>
<td>Molasses burner inlet pressure</td>
<td>bar(g)</td>
<td>16</td>
</tr>
<tr>
<td>Molasses concentration (tank)</td>
<td>brix</td>
<td>75</td>
</tr>
<tr>
<td>Viscosity before burner</td>
<td>cSt</td>
<td>54</td>
</tr>
<tr>
<td>Molasses temperature</td>
<td>°c</td>
<td>92</td>
</tr>
<tr>
<td>Furnace pressure</td>
<td>mmWC</td>
<td>4</td>
</tr>
<tr>
<td>Combustion air temperature</td>
<td>°c</td>
<td>180</td>
</tr>
<tr>
<td>Carbon monoxide on flue gases</td>
<td>ppm</td>
<td>30</td>
</tr>
<tr>
<td>Nitrogen oxides (NOx)</td>
<td>ppm</td>
<td>280</td>
</tr>
<tr>
<td>Carbon dioxide in flue gases</td>
<td>%</td>
<td>8.5</td>
</tr>
<tr>
<td>Oxygen in flue gases</td>
<td>%</td>
<td>5</td>
</tr>
</tbody>
</table>

Fig. 3—Sketch of the case study boiler at Araucaria.  
Fig. 4—Picture of the case study boiler at Araucaria.  
Fig. 5—Picture of burner for case study boiler at Araucaria.
Conclusion

When soy molasses and vinasse are burnt, only ash remains as a high-quality, odourless fertiliser that can be returned to the soil. This is an enormous benefit for the environment because nowadays the residue from soy and sugar production in Asia and Latin America is generally dumped on the area under cultivation.

This paper has shown that firing plants for soy molasses/vinasse offer an economical and ecological answer to the increasing and highly diversified industrial demand for alternative fuels. Various technological innovations and improvements now make it possible to utilise the potential heat energy available in by-products and waste from the sugarcane and bioethanol industries by firing them as alternative fuels instead of merely disposing of them. This means that, depending on the application, they can be used to replace, completely or partially, expensive standard fuels such as natural gas. In addition, CO₂ emissions from non-renewable fuel are considerably reduced as well.

REFERENCES


UTILISATION THERMIQUE DE LA VINASSE COMME CARBURANT DE REMPLACEMENT

Par

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MOTS-CLES: Vinasse, Mélasse, Production De Vapeur, Brûleur à Faible Turbulence.

Résumé

SAACKE a conçu un brûleur spécial pour les carburants biogènes qui sont générés comme des sous-produits, par exemple lors de la production de bioéthanol. Lorsque le soja et la mélasse de canne à sucre sont distillés après fermentation, pour la production de bioéthanol, mélasse et vinasse sont produites. Du point de vue de la combustion, mélasse et vinasse sont très similaires (40–50% d'eau, 40–50% les produits biologiques, environ 10% de cendres). Ce sont des sous-produits liquides avec une valeur calorifique extrêmement faible qui ne pouvaient être utilisés dans le passé pour produire de l'énergie. De nos jours avec le brûleur à faible turbulence, il est possible d'utiliser ces matériaux en forme concentrée en mélange avec 20% de carburant pour générer de la chaleur qui est à son tour réinjectée dans le procédé de production. Ainsi, 80 pour cent des carburants précédemment nécessaires à la production de bioéthanol peuvent être économisés. Lorsque la mélasse et la vinasse sont utilisées comme combustible il en résulte seulement des cendres qui constituent un engrais inodore, de haute qualité qui peut être incorporé au sol. Il s'agit d'un avantage immense pour l'environnement car de nos jours le résidu de la production de soja et de la canne à sucre en Asie et en Amérique latine, est généralement disposé sur les superficies cultivées. Le premier pas dans cette direction a déjà été fait en Araucaria dans l'état du Paraná au Brésil où la mélasse et la vinasse ont été utilisées à l'aide de brûleurs SAACKE depuis 2007.
EMPLEO TÉRMICO DE LAS VINAZAS COMO COMBUSTIBLE ALTERNATIVO

Por

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PALABRAS CLAVE: Vinazas, Melazas, Producción de Vapour, Quemador de Torbellino.

Resumen

SAACKE ha diseñado un quemador especial para el empleo de combustibles biogénicos que constituyen sub-productos, por ejemplo durante la producción de bioetanol. Cuando el mosto fermentado de soya o de caña de azúcar se destila para separar bioetanol se producen melazas y vinazas. Desde el punto de vista de la combustión las melazas y las vinazas son muy similares (40-50% de agua, 40–50% de orgánicos, cerca de 10% cenizas). Éstos son subproductos líquidos con un extremadamente bajo valor calórico que no podían ser empleados en el pasado para generar energía. Hoy el quemador de torbellino SSB-LCL hace posible emplear estos materiales concentrados, con adición de alrededor de 20% de combustible soporte, para generar calor, el que es retornado al proceso productivo. Como resultado, el 80% del combustible anteriormente requerido para producir bioetanol puede ahorrarse. Cuando las melazas y las vinazas se queman solo quedan cenizas como un fertilizante de alta calidad e inodoro que puede retornarse al suelo. Este es un enorme beneficio al ambiente, porque actualmente los residuos de la producción de soya y azúcar en Asia y Latinoamérica generalmente se arrojan en las áreas de cultivo. Los primeros pasos en esta dirección se han dado en Brasil, en Araucaria, en el estado de Paraná, donde las melazas y vinazas se queman empleando los quemadores SAACKE desde el 2007.
SUSTAINABILITY OF THE PRODUCTION OF ETHANOL FROM SUGARCANE: THE BRAZILIAN EXPERIENCE

By

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KEYWORDS: Biofuels, Sustainability, Certification, Sugarcane, Greenhouse Gases.

Abstract

The increase in production of liquid biofuels from different feedstocks is causing concern for potential importers and users, as an alternative to reduce greenhouse gas (GHG) emissions. The sustainability of the whole production chain of each biofuel is under review. Some countries, especially in the European Union (EU), are jumping ahead in the process of preparing certification procedures to assure the sustainability of the different alternatives under consideration; this is the beginning of the process to show that all biofuels are not equal. Ethanol from sugarcane has demonstrated, so far, superiority over other biofuels (ethanol from grains or sugar beet, and biodiesel from soybeans or rapeseed), but the demonstration process must be clear and based on measurable parameters. Surplus power generation is an important point to improve the energy and Green House Gas (GHG) balances, increasing the value of ethanol in the GHG abatement process when it displaces the use of gasoline as a transport fuel. Brazil as a major producer and exporter of ethanol from sugarcane is working hard to demonstrate the sustainability of its ethanol, using reliable information, well established procedures and participating in the worldwide effort to produce certification standards. Net energy ratios above eight and GHG abatement efficiency better than 80% for the Brazilian production and use chain have been demonstrated. This paper presents a comprehensive assessment of this Brazilian work toward the demonstration of sugarcane ethanol sustainability, offering some insights and lessons for other countries starting in this process.

Introduction

The fast increase in the production of liquid biofuels from different feedstocks is becoming a cause of concern to the major users, especially with respect to the most important expected benefits, such as Greenhouse Gas (GHG) emission reduction in transport, and the sustainability of the whole production chain of each biofuel alternative.

As a consequence, several countries in the European Union and the USA are starting to develop certification procedures to make sure that the biofuel options under consideration are sustainable and really contribute significantly to the reduction of GHG emissions in the transport sector. This represents a considerable effort in preparing paperwork to demonstrate the carbon footprint and the other important characteristics of the specific biofuel with respect to its sustainability and contribution to global warming mitigation.

Figure 1 shows the growth of biofuels production from 2000 to 2005 (IEA, 2007), and it is a clear indication that choices have to be made at this stage to avoid embarking in a biofuel alternative without future–it is the realisation that biofuels are not equal; not only the biofuel itself, but also the feedstock used in its production. The main driving forces behind the production and use of biofuels are:
Energy security: the volatility of oil prices since 2002 and the political instability in some major oil producing countries are threats for the economies of countries that depend on oil imports.

GHG emission reduction: the transport sector is responsible for 14% of the global GHG emissions and, therefore, the substitution of renewable fuels for fossil fuels has an enormous potential for mitigation.

Rural jobs: the potential of biofuels production to increase the demand for agricultural products has attracted the interest of many countries, especially developing ones, to use this option to strengthen their rural economies and to create jobs in agriculture.

For the countries interested in producing biofuels for export, there are some additional points that need to be evaluated: the potential of biofuel use and which countries are an important target; regulations and certification activities underway in these countries; scenarios for future use of biofuels.

Considering the case of ethanol, the present use of gasoline is an indication of the potential for use of this renewable fuel. Table 1 presents the main gasoline consumers in the world.

### Table 1—Main gasoline consumers in the world

<table>
<thead>
<tr>
<th>Country</th>
<th>Gasoline consumption (million m³/year)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>517</td>
<td>42.6</td>
</tr>
<tr>
<td>EU-27</td>
<td>143</td>
<td>11.8</td>
</tr>
<tr>
<td>China</td>
<td>71</td>
<td>5.8</td>
</tr>
<tr>
<td>Japan</td>
<td>60</td>
<td>4.9</td>
</tr>
<tr>
<td>OECD</td>
<td>836</td>
<td>68.8</td>
</tr>
<tr>
<td>World</td>
<td>1215</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Source: IEA (2009)
Methodology

In this section, the main points are reviewed for selecting biofuel options and compared with the main characteristics of the Brazilian ethanol with respect to sustainability issues. Although the main focus of this work is on ethanol, in many instances biofuels will be treated in a similar way, because they all compete with ethanol in the liquid transport fuel market.

Certification initiatives

As explained above, the USA and EU countries are the ones with the highest potential for producing, using and importing biofuels, and for this reason will be the ones focused in this section.

USA


The RFS mandates the use of renewable transport fuels in an increasing proportion, reaching a total of 136 billion litres (36 billion US gallons) per year in 2022 and divides the biofuels in four different categories: renewable fuel, advanced biofuel, biomass-based diesel and cellulosic biofuel; the 136 billion litres are allocated to each category as 15, 4, 1 and 16 billion US gallons, respectively. The US Environmental Protection Agency can change these quantities in the future. The eligibility requirements for each category include the mandatory GHG reduction thresholds of 20%, 50%, 50% and 60% for renewable fuel, advanced biofuel, biomass-based diesel and cellulosic biofuel, respectively. First generation biofuels such as sugarcane ethanol can be in the advanced biofuel category if it satisfies the GHG reduction threshold. The California GHG target is 10% over the 1990 emissions level in the transport sector. In all cases, the GHG reduction is in comparison with gasoline.

EU

The Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the Promotion of the Use of Energy from Renewable Sources (Official Journal of the European Union, L140/16, 5.6.2009) establishes mandatory targets of 20% share of renewable energy sources in energy consumption and a minimum of 10% for biofuels in transport to be achievable for each Member State. Extensive procedures to calculate GHG reductions are described and the Sustainability Criteria for Biofuels and Bioliquids are indicated in Article 17 of the Directive. The threshold limits for GHG reductions are set at 35% for plants coming into production from 2010 and will be increased to 50% for plants starting up in 2017 and 60% in 2018 (the existing plants will have to satisfy the limit of 50% minimum reduction).

There are other important certification initiatives in progress such as the Renewable Transport Fuel Obligation (RTFO) in the UK and the Cramer Report in Holland (Cramer et al., 2007), Roundtable of Sustainable Biofuel (RSB) in Switzerland, and Global Bioenergy Partnership (GBEP) coordinated by the UK.

The Better Sugarcane Initiative (BSI) mission is to ensure that current and new sugarcane production is produced sustainably (www.bettersugarcane.org) and is preparing the BSI Standard that is presently going through a public consultation process. Of all initiatives on biofuels sustainability, the BSI is the most specialised in sugarcane and depends on Technical Working Groups with reputable members of the international sugarcane sector to assist in the development of its work.

Key issues

From the analysis of the main biofuels certification initiatives, the key issues for sustainability can be selected for a more detailed assessment:

- Energy balance: it is normally represented by the Net Energy Ratio–NER (renewable energy output of biofuel and co-products divided by the fossil energy input in the
whole production chain). The NER gives a good indication of the capacity of the biofuel to reduce the dependency on fossil energy and can be extended to indicate the oil use in the process.

- Greenhouse Gas mitigation potential: this is presently the main characteristic of the biofuel to contribute to the global warming mitigation; it is an indication on how efficient and competitive it is in this process, for the abatement cost can be easily calculated. The procedures and standards to perform the so called GHG lifecycle analysis (LCA) are yet to be universally defined and accepted; a search in the technical literature shows a wide variation for different biofuels and even for the same biofuel and feedstock (Larson, 2006), mainly due to system boundaries definition, co-products credits calculation, soil emissions and land use change emissions.

- Demand for natural resources: it has to do, mainly, with the land and water demand, and is the key point in the, more emotional than technical, discussions about the impacts of biofuels on the food and feed availability and prices. Therefore, the productivity of the feedstock/biofuel pair in terms of litres/ha, or better GJ/ha, is very important as well as the ability to use rain-fed crops. A careful Agro-ecological Zoning of the main feedstocks is an important tool to demonstrate the ability to produce the biofuels without jeopardising the food and feed production.

- Production cost: there is no doubt that the economic leg of the Sustainability triad is the strongest one and, for this reason, the production cost of the biofuel, preferably measured in terms of US$/litre of gasoline or diesel equivalent, is the best indication if it will be able to compete with fossil fuels and other renewable energy alternatives to reduce GHG emissions, without subsidies in the long term; the parameter here will be US$/tonne CO2 equivalent.

- Impacts on biodiversity: a good Agro-ecological Zoning for the feedstocks will solve most of the problems and doubts. Just by avoiding planting in sensitive areas can be an important step to satisfy the requirements in this area.

- Social impacts: this issue is difficult to quantify. Procedures need to be developed to assess the impacts of the biofuel production on jobs, wealth of the local communities, labour issues, land ownership and others.

- Local environmental impacts: this is easier to monitor and quantify than the social impacts, but nevertheless it brings some challenging issues such as water contamination, soil quality and loss, waste management and air emissions.

There are other topics normally included in the certification procedures being proposed, but the above are the ones normally present in all initiatives.

The Brazilian experience

Having a long tradition in and being the second largest producer and user of ethanol in the world has brought to Brazil some valuable experiences that can be used by other countries to avoid repeating some of our mistakes and to indicate the shortest route to success. Of course this does imply that the Brazilian model can be used as is by any country. Each country has its own culture, experiences, laws and regulations and talents that need to be taken into account.

In sequence, the several indexes and conditions in the Brazilian ethanol production chain will be described and, where possible, quantified.

Energy balance

The energy balance in the ethanol production in Brazil has been analysed since the 1980s bringing some insights to the evolution and critical points for improvements (Macedo and Nogueira, 1985; Macedo, 1992). The methodology was consolidated by Macedo et al. (2004) and updated by
Macedo et al. (2008) with projections for 2020. In all these references, three levels of energy were considered: (a) Level 1: energy consumed directly in the feedstock production and processing such as fuels and electricity; (b) Level 2: energy required for the production of chemicals and materials (fertilisers, herbicides, seeds, chemicals, lubricants, etc.); (c) Level 3: energy embodied in the equipment and buildings and consumed in their maintenance.

A summary of the results is presented in Table 2.

Table 2—Energy consumption in ethanol production (MJ/t cane).

<table>
<thead>
<tr>
<th>Item/Reference year</th>
<th>2002</th>
<th>2005</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural operations</td>
<td>16.4</td>
<td>13.3</td>
<td>14.8</td>
</tr>
<tr>
<td>Harvesting</td>
<td>21.6</td>
<td>33.3</td>
<td>46.9</td>
</tr>
<tr>
<td>Cane transportation</td>
<td>39.0</td>
<td>36.7</td>
<td>44.8</td>
</tr>
<tr>
<td>Inputs (chemicals, etc.) transp.</td>
<td>4.0</td>
<td>10.9</td>
<td>13.5</td>
</tr>
<tr>
<td>Other field activities</td>
<td>–</td>
<td>38.5</td>
<td>44.8</td>
</tr>
<tr>
<td>Sub total</td>
<td>81.0</td>
<td>132.7</td>
<td>164.8</td>
</tr>
<tr>
<td>Fertilisers</td>
<td>66.5</td>
<td>52.7</td>
<td>40.0</td>
</tr>
<tr>
<td>Lime, herbicides, insecticides.</td>
<td>19.2</td>
<td>12.1</td>
<td>11.1</td>
</tr>
<tr>
<td>Seeds</td>
<td>5.9</td>
<td>5.9</td>
<td>6.6</td>
</tr>
<tr>
<td>Sub total</td>
<td>91.6</td>
<td>70.7</td>
<td>57.7</td>
</tr>
<tr>
<td>Machinery</td>
<td>29.2</td>
<td>6.8</td>
<td>15.5</td>
</tr>
<tr>
<td>Sub total</td>
<td>29.2</td>
<td>6.8</td>
<td>15.5</td>
</tr>
<tr>
<td>Total for cane production</td>
<td>201.8</td>
<td>210.2</td>
<td>238.0</td>
</tr>
<tr>
<td>Cane processing chemicals</td>
<td>6.4</td>
<td>19.2</td>
<td>19.7</td>
</tr>
<tr>
<td>Buildings</td>
<td>12.0</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Equipment</td>
<td>31.1</td>
<td>3.9</td>
<td>3.9</td>
</tr>
<tr>
<td>Total for cane processing</td>
<td>49.5</td>
<td>23.6</td>
<td>24.0</td>
</tr>
<tr>
<td>Total for the production chain</td>
<td>251.3</td>
<td>233.8</td>
<td>262.0</td>
</tr>
</tbody>
</table>

Source: Macedo et al. (2008)

The differences between 2002 and 2005 are mainly due to an update of the facilities configuration, diesel consumption and embodied energy coefficients. Between 2005 and 2020, the projected differences are due to sugarcane burning phase out, gains in sugarcane yield and sugar content, and technological improvements.

The input/output energy balance is shown in Table 3, based on the average conditions in the Center-South region (90% of sugarcane production in Brazil)

Table 3—Energy balance for the ethanol production chain—renewable energy out/fossil energy in (MJ/t cane).

<table>
<thead>
<tr>
<th>Item/Reference year</th>
<th>2002</th>
<th>2005</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossil energy in</td>
<td>251.3</td>
<td>233.8</td>
<td>262.0</td>
</tr>
<tr>
<td>Renewable energy out</td>
<td>2090.0</td>
<td>2185.2</td>
<td>3032.3</td>
</tr>
<tr>
<td>Ethanol</td>
<td>1921.3</td>
<td>1926.4</td>
<td>2060.3</td>
</tr>
<tr>
<td>Surplus bagasse</td>
<td>168.7</td>
<td>176.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Surplus electricity</td>
<td>0.0</td>
<td>82.8</td>
<td>972.0</td>
</tr>
<tr>
<td>Renewable output/fossil input</td>
<td>8.3</td>
<td>9.3</td>
<td>11.6</td>
</tr>
</tbody>
</table>

Source: Macedo et al. (2008)
The details of this energy balance can be found in the reference (Macedo et al., 2008). The data presented in Table 3 show an excellent energy balance, and the methodology presented in the references can be used by any country to do its own energy balance and compare with the Brazilian one in detail.

**GHG lifecycle analysis (LCA)**

The GHG lifecycle analysis (LCA) derives mainly from the energy balance but there are non-energy related emissions that must be taken into account such as CO₂, methane and NO₂ emissions from cane burning, fertiliser, lime and residue decomposition, and soil carbon stock modification due to land use change. Table 4 presents a GHG LCA for the Brazilian conditions with projection for 2020 for anhydrous ethanol; the emissions due to direct and indirect land use change (LUC and ILUC) are not included due to the dependence on the local conditions (soil, climate, previous use of the land, specific agricultural practices, etc.) and the cause/effect relationship in the case of indirect land use change emissions.

<table>
<thead>
<tr>
<th>Item/Reference year</th>
<th>2002</th>
<th>2005</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total emissions</td>
<td>401</td>
<td>436</td>
<td>345</td>
</tr>
<tr>
<td>Fossil fuels</td>
<td>223</td>
<td>210</td>
<td>219</td>
</tr>
<tr>
<td>Trash burning</td>
<td>105</td>
<td>84</td>
<td>0</td>
</tr>
<tr>
<td>Soil emissions</td>
<td>73</td>
<td>143</td>
<td>126</td>
</tr>
<tr>
<td>Avoided emissions1</td>
<td>2401</td>
<td>2323</td>
<td>2930</td>
</tr>
<tr>
<td>Use of ethanol</td>
<td>2256</td>
<td>2111</td>
<td>2111</td>
</tr>
<tr>
<td>Use of surplus biomass</td>
<td>145</td>
<td>150</td>
<td>0</td>
</tr>
<tr>
<td>Surplus electricity</td>
<td>0.0</td>
<td>62</td>
<td>819</td>
</tr>
</tbody>
</table>

Source: Macedo et al. (2008)
Note: 1 Displacing gasoline by the use of E25

It is interesting to look into the details of the analysis summarised in Table 4 in Macedo et al. (2008). It can be seen that, like in the energy balance, the agricultural area is the major source of GHG emissions and sugarcane yield plays a major role in the balance.

**Demand for natural resources**

In Brazil, sugarcane cultivation is mainly rain fed, although there is a trend to increase the use of irrigation in some dry areas such as the Northeast states and some areas in the new sugarcane frontier in the Center states savannah. The Agro-ecological Zoning of sugarcane will inhibit the expansion in these areas and the development and use of drought-tolerant varieties will help those already installed in these regions.

In most cases, only the salvatin irrigation is used (less than 200 mm/year, and is intended only to keep the sugarcane from dying during an unusually dry spell), but full irrigation alternatives are being evaluated in a few cases.

The water intake for use in the mill is being continuously reduced in Brazil, especially in São Paulo, where the value of 1 m³/t of cane was set as a limit for new mills being installed in the state; the average value for the Center/South region has been reduced from 5 m³/tc to 1.8 m³/tc in the past few years, motivated by the legislation that will introduce payments for water consumption and effluent discharge.

The water use main regulatory item is the Federal Law 9433 of 1997 that establishes the National Resource Policy and the National Water Resources Management System. This Federal law is complemented by several state level laws and regulations that create additional requirements and constraints.
Sugarcane is one of the most productive crops for biofuel production; under the present Brazilian average conditions, some 150 GJ/ha/y of renewable fuel (6500 litres of ethanol/ha/y). This figure can be significantly improved by the increase in sugarcane yields, better agricultural practices (such as precision agriculture, no tillage, maximum use of residues in the fields), optimum use of the sugarcane biomass (power generation and/or advanced technologies for biomass to liquids, BTL, for additional biofuel production).

In Brazil, the expansion of sugarcane cultivation is taking place mostly in pasture lands. There is a growing interest in developing and using technologies to intensify the cattle husbandry activities in terms of reducing land demand through increasing the number of cows per hectare. The integration of cattle and sugar/ethanol mills is also being investigated, with respect to the possibility of the mills to produce cattle feed from bagasse (hydrolysed), molasses and dried yeast.

This intensification process is proceeding in some areas, like the state of São Paulo, and creating a tremendous potential for new areas for sugarcane, without impacts on food/feed production or deforestation, since presently the pasture area is around 200 million hectares; just 10% of that would be sufficient for the sugarcane expansion foreseen for a few decades.

Even bearing in mind that water is an important and critical resource, the use of irrigation should not be ruled out to reduce the land demand and the fossil fuel consumption in the ethanol production chain. It is expected that the Agroecological Zoning, that has been recently approved, will regulate and orient the sugarcane expansion and decrease the impacts on and pressures for land demand.

Today, sugarcane occupies 8 Mha and, bearing in mind that only 55% of that is for ethanol production, the 4.4 Mha devoted to bioethanol represents only 0.5% of the total country area or 7% of the total cultivated land.

Production cost

The economics of biofuels is certainly the most important item in the long-term sustainability of each alternative without subsidies. It is important also to point out that subsidies tend to distort the market balance between production for food/feed and fuel of the agricultural feedstock.

In the case of Brazilian ethanol, a parity price to make it unimportant to produce either sugar or ethanol was a key point at the beginning of the National Ethanol Program back in 1975. The ethanol subsidies were highly reduced in the mid 1980s, and were totally phased out at the end of the 1990s.

The sugar/ethanol parity price was terminated in 1995. In this way, there has never been a sugar shortage, neither for the internal market nor for export, since sugar has always been a better market product than ethanol. Ethanol had its learning curve effect that resulted in a significant production cost reduction (van den Wall Bake, 2006) as shown in Figure 2.

It is expected that further cost reductions are still achievable in this learning curve, due mainly to gains in scale, improved management, precision agriculture, no or minimum tillage, commercial use of transgenic sugarcane and the efficient use of the biomass residues to generate surplus power and/or for second generation biofuels production.

Impacts on biodiversity

Since it is difficult to precisely define and quantify the impacts on biodiversity, the reference on this matter found in the initiatives to produce certification procedures remain vague, stating generally that some attention should be paid to this item.

The most frequent mention is that biofuel feedstocks shall not be grown on areas of high biodiversity value and protected areas. Agro-ecological Zoning could take care of the biodiversity preservation issue by ruling out the use of high biodiversity and sensitive areas. Just by avoiding deforestation, a lot of the ground is covered toward this goal.
In Brazil, there are laws protecting the biodiversity rich areas but the enforcement of these laws is still very loose. Since most of the expansion of sugarcane plantations is taking place on pasture and soybeans areas, the negative impacts on biodiversity are being minimised.

**Social impacts**

The observation of the human rights issues, commitment with the International Labor Organisation (ILO) and local workers organisation agreements are the key topics in the social impacts. Other important items are wages, working conditions, child and slave labour, land rights and competition with food production and jobs (in quantity and quality).

The Brazilian workers of the sugarcane sector are reasonably protected by the existing laws and regulations and, although the enforcement of the legislation is not adequate in some regions, we can say that there are no major problems in the sector compared with other sectors of agriculture (Macedo, 2005).

Government authorities, NGO’s members and even the Catholic Church look after the social issues in the country. If all existing laws were enforced, there would be no problem in this area in Brazil. Just to exemplify one aspect, the mean income of the sugarcane sector is compared with other representative sectors of the country’s economy and the numbers are shown in Table 5 (Macedo, 2005).

**Table 5**: Mean income in all jobs for people occupied or engaged in sugarcane sector and other industries in Brazil (2003).

<table>
<thead>
<tr>
<th>Items</th>
<th>Sugarcane</th>
<th>Sugar</th>
<th>Ethanol</th>
<th>Food and beverage</th>
<th>Fuels</th>
<th>Chemicals</th>
</tr>
</thead>
<tbody>
<tr>
<td>People x1000</td>
<td>789.4</td>
<td>126.0</td>
<td>67.0</td>
<td>1507.0</td>
<td>104.7</td>
<td>641.2</td>
</tr>
<tr>
<td>Mean age (years)</td>
<td>35.1</td>
<td>36.6</td>
<td>35.6</td>
<td>34.4</td>
<td>37.1</td>
<td>33.4</td>
</tr>
<tr>
<td>Education (years)</td>
<td>2.9</td>
<td>6.5</td>
<td>7.3</td>
<td>7.1</td>
<td>8.9</td>
<td>9.6</td>
</tr>
<tr>
<td>Mean income (R$/month)</td>
<td>446.6</td>
<td>821.3</td>
<td>849.9</td>
<td>575.0</td>
<td>1281.1</td>
<td>1074.6</td>
</tr>
</tbody>
</table>

Source: Macedo (2005)

![Cumulative ethanol production (10^6 m³)](image-url)

*Fig. 2—Sugarcane and ethanol learning curves—the Brazilian case*

These data show that the agriculture part of the production chain presents an unfavourable condition when compared with its factory part and other industrial sectors. With the increase of mechanisation in the agricultural operations (harvesting and planting), the situation tends to improve with the change of many low pay/hard work jobs by a smaller quantity of better paid and more stable jobs.

Local environmental impacts

Cane burning phase out in the states of São Paulo and Minas Gerais (approximately 2/3 of the total Brazilian cane) will be nearly accomplished by 2014 and totally finished by 2017, according to the Environmental Protocols signed by representative of the state government, cane growers, mill owners and workers representatives. Other important items such as improved working conditions, workers’ qualification (cane cutters are being trained to perform more qualified functions in the mechanisation system), environmental conditions improvement, etc. Other states will probably follow suit and make similar agreements, resulting in a considerable reduction of negative environmental impacts, especially those derived from cane burning. Green cane harvesting will also decrease soil erosion, agrochemicals carryover to surface water and leaching to ground water and will create the adequate conditions to develop no tillage systems that will reduce even further the negative impacts on soil, air and water.

Final comments

The brief description of the differences in biofuels with respect to long-term sustainability issues and a quick look at the Brazilian experiences will hopefully help the potential biofuels producers to make a more technical decision about the best option for the local conditions.

The first points to be analysed have to do with the level of contribution to the GHG emission reductions (in terms of % of the equivalent fossil fuel emissions), the production costs (an indicator of the economic viability, or US$/t CO₂ eq. and US$/litre of gasoline/diesel equivalent) and the natural resources demands for the full dimension of the specific biofuel program. If the biofuel passes this first battery of tests, it can then go to the next steps of evaluation that are: social issues, impacts on biodiversity and environment. A clear view of the necessary public policies and the investments required to bring the program to a self-sustained level is a must to have a stable biofuel program on line.

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LA DURABILITÉ DE LA PRODUCTION D'ÉTHANOL À PARTIR DE SUGARCANE: L'EXPÉRIENCE BRÉSILIENNE

Par

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MOTS-CLÉS: Biocarburants, Durabilité, Certification, Sugarcane, les Gaz à Effet de Serre.

Résumé

L'AUGMENTATION de production de biocarburants liquides à partir de différents substrats est une source de préoccupation pour les importateurs éventuels et les utilisateurs dans le cadre des solutions alternatives pour la reduction des émissions de gaz à effet de serre (GES). La durabilité de l'ensemble de la chaîne de production de chaque biocarburant est sous étude. Certains pays, en particulier ceux de Union Européenne (UE), vont de l'avant dans la préparation des procédures de certification afin d'assurer la durabilité des différentes alternatives proposées; c'est le début du processus pour démontrer que tous les biocarburants ne sont pas égaux. L'éthanol produit à partir de la canne à sucre a démontré à ce jour sa supériorité sur les autres biocarburants (éthanol de betterave à sucre ou de céréales) et le biodiesel de soja ou de colza, mais la démonstration du procédé doit être évidente et basée sur des paramètres quantifiables. La production d'énergie excédentaire est un point important pour améliorer l'équilibre entre la production d'énergie de celle de GES, de ce fait augmentant la valeur de l'éthanol dans le processus de réduction des GES lorsqu'il déplace l'utilisation de l'essence comme un combustible de transport. Le Brésil comme un producteur et exportateur majeur d'éthanol à partir de la canne à sucre s'efforce à démontrer la durabilité de l'éthanol, à l'aide d'une information fiable, des procédures bien établis et à travers la participation à l'effort à travers le monde entier pour produire des normes de certification. Des rapports d’énergie supérieurs à huit et des reductions GES supérieures à 80% ont été démontrés à travers la chaîne de production au Brésil. Cette communication présente une évaluation complète des travaux exécutés au Brésil pour démontrer la durabilité de la production d'éthanol à partir de la canne à sucre, propose certaines idées et des enseignements utiles pour les autres pays qui s'apprent à se lancer dans ce processus.
SOSTENIBILIDAD DE LA PRODUCCIÓN DE ETANOL DE LA CAÑA DE AZÚCAR: LA EXPERIENCIA BRASILEÑA.

Por

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PALABRAS CLAVE: Biocombustibles, Sostenibilidad, Certificación, Caña de Azúcar, Gases de Efecto Invernadero.

Resumen

EL AUMENTO de la producción de biocombustibles líquidos a partir de diferentes fuentes está generando preocupación en potenciales importadores y usuarios, como una alternativa para reducir la emisión de gases de efecto invernadero (GHG). La sostenibilidad de la cadena total de producción de cada biocombustible está bajo escrutinio. Algunos países, especialmente en la Unión Europea, están saltando adelante en el proceso de preparación de procedimientos de certificación para asegurar la sostenibilidad de las diferentes alternativas bajo consideración, este es el inicio del proceso para demostrar que no todos los biocombustibles son iguales. El etanol de la caña de azúcar ha demostrado, hasta ahora, superioridad sobre otros biocombustibles (etanol de granos, de azúcar de remolacha y bio diesel de soya ó colza), pero el proceso de demostración debe ser claro y basado en parámetros medibles. La generación de energía sobrante es un punto importante para mejorar el balance de energía y de gases de efecto invernadero (GHG), aumentando el valor del etanol en el proceso de abatir los GHG cuando desplaza el uso de la gasolina como combustible automotor. Brasil, como mayor productor y exportador de etanol a partir de la caña de azúcar, está trabajando fuerte para demostrar la sostenibilidad de su etanol, empleando información confiable, procedimientos bien establecidos y participando en el esfuerzo mundial para elaborar estándares certificables. Se han demostrado relaciones de energía neta por encima de ocho y eficiencias de abatimiento de los GHG mejores del 80% para la producción y la cadena de usos brasileña. El artículo presenta una explicación comprensible de este trabajo brasileño dirigido a la demostración de la sostenibilidad del etanol de la caña de azúcar, ofreciendo apreciaciones y lecciones para otros países que inician este proceso.
ALCOHOLIC FERMENTATION WITH TEMPERATURE CONTROLLED BY ECOLOGICAL ABSORPTION CHILLER—EcoChill

By

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KEYWORDS: Alcoholic Fermentation, Temperature, Ethanol, Absorption Chiller.

Abstract

THE FERMENTATION process in ethanol production is where less efficiency and more losses can be found. One of the operational parameters that maximises ethanol production is the control of the fermentation temperature to maintain it at the optimum point. Usually the cooling systems are comprised of evaporative coolers where the lowest temperature that can be reached is a function of the wet bulb temperature. Thus, in tropical countries like Brazil, the temperature in fermentation normally reaches values above 32°C and can reach 36°C in hot periods. This condition has a negative effect in the cellular metabolism reducing ethanol productivity and damaging the viability of cells. To determine the engineering parameters to optimise the ethanol fermentation process in industrial scale designs, Dedini S/A built and installed a semi-industrial demonstration plant in a sugar and ethanol mill of the Cosan Group. The main parameter of the experiments was the control of the fermentation temperature, which ranged from 28°–32°C, as a function of the ethanol content increase and the influence of feedstock in the fermentation yield. The results obtained show that there was a significant increase of alcohol concentration in fermented mash, which reached about 16°GL at 29°C. Thus, increasing ethanol concentration leads to a decrease in steam demand for distillation and a big reduction in volume of vinasse generated. The low temperature of mash leads to a low level of contaminants, assuring good quality and greater fermentation yield. The lithium-bromide absorption chiller operated effectively, indicating that it is a proven product for application in ethanol production.

Introduction

Several references in literature (Dias et al., 2007; Jones et al., 1981; Prescott and Dunn, 1987; Yamakawa, 2008) report a high concentration of ethanol in the fermentation broth from most diverse sucrose feeds (sugarcane, wheat, corn and rice). Operating ethanol fermentation in high concentrations fundamentally increases industrial productivity, reduces steam and utilities consumption, and minimises losses with contaminants and, especially, reduces the volume of vinasse generated. Vinasse requires significant resources for final disposal.

Fermentation is a unit operation in ethanol production in which there is less efficiency and, consequently, greater loss. One of the parameters directly involved is the temperature. The biochemical reaction of converting sugar into ethanol is an exothermic reaction; usually, the Brazilian ethanol plants use water from a closed circuit evaporative cooling system to control the temperature of fermentation by indirect exchange. The evaporative cooling naturally undergoes a change depending on the wet bulb temperature and, in tropical countries like Brazil, the lowest temperature of cooling water is 29°C (Prescott and Dunn, 1987).
In different environmental and nutritional conditions, the yeasts can adopt distinct metabolic routes for the production of different compounds. In anaerobic conditions, glucose can be converted into ethanol, acetic acid, lactic acid and carbon gas. One of the factors associated with the yeast’s preferred reaction is temperature, and there are many references in literature defining that the most favourable temperature for converting sugar into ethanol is below 32°C:

- Rivera et al. (2006): considered temperature as the variable to evaluate the optimum expected parameters of ethanol fermentation; based on experimental data, maximum ethanol production is achieved at 28°C–31°C.
- Prescott and Dunn (1987): found that the optimum temperature for cell growth and ethanol production is 30°C, but higher temperatures (35°C ~38°C) are acceptable. However, at these temperatures, cell growth rate, ethanol production and death rate can be affected negatively.
- Jones et al. (1981): reported that the S. cerevisiae yeast can bear up to 33°C in industrial conditions for ethanol production; minimum growth range is 10°C and the maximum is 40°C, and the optimum temperature is between 28°C and 35°C.
- Dias et al. (2007): reported that high temperatures in fermentation affect the yeasts metabolism and reduces the ethanol concentration in the final broth, which increases steam consumption in distillation. Fermentation at 28°C allows operation with higher concentration sugars in the must, and this reduces the steam consumed in distillation and vinasse generation (5.76 L/ L EtOH).

Therefore, there is a great indication that the fermentation conducted at a controlled temperature below 32°C will result in an increased industrial yield and also will provide the very high gravity fermentation. However, all these studies and conditions are for small scale experiments. To effectively evaluate the optimised temperature of the ethanol fermentation in industrial conditions and scale, in 2008 DEDINI built and operated a 20 000-L ethanol/day demonstration plant with temperature control at 28°C and 32°C. An absorption chiller made by THERMAX was used for this purpose. The results indicate that temperature in the range of 28°C to 30°C is the most appropriate to obtain high alcohol content.

**Process description**

A detailed description of the cooling system process by the steam absorption chiller cooling system and the process of alcoholic fermentation is presented.

**Absorption chiller cooling system**

The goal of the cooling system by absorption chiller is to chill water in the range of 16 to 20°C for controlling the temperature of fermentation in the range of 28 to 32°C. Figure 1 represents the diagram of the refrigeration cycle steam absorption by the solution of lithium bromide. This system uses the principle of vacuum and the capacity of the solution of lithium bromide to absorb steam. The absorption cycle involves three circuits: the cooling water is pumped to the evaporator (1), the lithium bromide used as absorbent flows over the tubes of the evaporator through the heat exchanger for the generator, the cooling water flows in series initially through the tubes of the absorber (1) and partly through the tubes of the condenser (3).

The water to be chilled enters the tubular bottle evaporator (1) where it is chilled indirectly by water spray. The steam is absorbed by a concentrated solution of lithium bromide at low pressure in the absorber (1). Lithium bromide having absorbed the steam is then pumped to the generator (2) to reconstitute the diluted solution. In generator (2) the solution is heated indirectly by hot water at low pressure for concentrating the salt solution before it enters the absorber. The flow of solution coming from the generator (2) goes to the absorber (1) by the difference in gravity and pressure. The water from the generator (2) by boiling is then condensed with cooling water, becomes liquid in the condenser section (3) and condensed back to the evaporator (1).
The application of the absorption chiller in the ethanol process is the reuse of non-thermal sources such as vinasse, flegmass or low steam pressure, replacing the current of hot water in the absorption circuit as shown in Figure 1.

In the case of the demonstration plant, the heat source is the vinasse after the process of regenerative heating of the wine in the distillation column. The temperature range of the waste is 80 to 85°C and the range flow is 100 to 150 m³/h.

**Alcoholic fermentation process**

The process assumed in this work was fed batch fermentation prepared with juice, syrup and molasses from cane sugar and with cell recycle *Saccharomyces cerevisiae*.

In Figure 2, the process flowchart of the demonstration plant Dedini installed at Usina Bom Retiro is presented.
The process begins with the sterilisation of the fermentor (FE-101) and peripherals such as tabulations, heat exchangers and pumps. At the same time, the yeast is reactivated by an acid treatment maintained under aeration and agitation for a period of 30 minutes in a pre-fermentor (PF-101). Then the yeast is transferred to the clean fermentor. The feed was started with set process parameters for temperature and percentage of sugar in the must. The feed is prepared and controlled by addition of juice, molasses, syrup and water in a static mixer (MT-101).

The must flow is controlled such that the biochemical reaction of converting sugars into ethanol does not result in inhibition by substrate, thus slowing the reaction. In this work the flow feed was 6 to 12 m³/h.

The temperature control is enabled when feeding of the sugar solution starts. The temperature transmitter (TT-01) is located in the fermentor and it provides the temperature of the controller (TIC-01) which compares with the value set-point and thus modulates the percentage of opening control valve (TCV-01).

Upon completion of the batch, the wine is discharged to the centrifugal separator (CT-101) and the clarified phase (wine) is sent to the distillation process and the heavy phase (cream yeast) is sent to the pre-fermentor (PF-101) to be treated and reactivated. Then, after the sterilisation process, the yeast returns to the fermentor (FE-101) for a new batch.

**Materials and methods**

In 2008/09 milling season, Dedini S/A Indústrias de Bases built and operated a demonstration plant, with nominal capacity to process 20000 litres of ethanol/day (Figure 3), equipped with a 100-m³ stainless steel fermentor, one 300 TR Thermax absorption chiller and one 315 m³/h evaporative cooling tower. The plant is located at COSAN, Usina Bom Retiro, in Capivari city, state of São Paulo.

The way to get very high gravity fermentation is to increase the amount of sugar in the must by the addition of molasses or syrup. In the 2008 milling season, we used 2 and 3 molasses to raise the alcohol content of the final wine. In the 2009 milling season, we used syrup. The molasses resulting from boiling, comprised of two massecuites, presents higher purity when compared with the molasses from boiling of three massecuites, which is usually called final molasses. Table 1 shows the comparison of the quality of the raw material of juice.
Table 1—Comparison of the raw material quality.

<table>
<thead>
<tr>
<th></th>
<th>Brix %</th>
<th>Pol %</th>
<th>Purity %</th>
<th>TRS %</th>
</tr>
</thead>
<tbody>
<tr>
<td>B Molasses (2 massecuites)</td>
<td>80.40</td>
<td>52.15</td>
<td>64.86</td>
<td>62.50</td>
</tr>
<tr>
<td>C Molasses (3 massecuites)</td>
<td>79.80</td>
<td>46.68</td>
<td>58.80</td>
<td>59.56</td>
</tr>
<tr>
<td>Syrup</td>
<td>55.00</td>
<td>47.85</td>
<td>87.00</td>
<td>50.00</td>
</tr>
</tbody>
</table>

Thus, the must made from molasses will have a lower quality when compared to wine made from syrup. Henceforth, the terms B and C molasses are called only molasses.

**Results and discussions**

We present the main results obtained since the start of operation of the demonstration plant until the middle of 2009. The results were divided into two groups according to the raw material used to prepare the must: molasses and syrup.

**Must from molasses**

Figure 4 shows the result of the fed batch prepared with molasses and controlled temperature of 28°C. The average percentage of ethanol is 9.59°GL and the average standard deviation is 1.1%.

![Fig. 4—Percentage of ethanol in batches conducted with molasses at 28°C.](image)

Figure 5 shows the result of the fed batch prepared with molasses and controlled temperature of 30°C. The average percentage of ethanol is 11.98°GL and the average standard deviation is 1.2%.

![Fig. 5—Percentage of ethanol in batches conducted with molasses at 30°C.](image)
Figure 6 shows the result of the fed batch prepared with molasses and controlled temperature of 32°C. The average percentage of ethanol is 11.37°GL and the average standard deviation is 1.2%.

The results of fermentation temperatures controlled at 28, 30 and 32°C show that it is feasible to obtain alcohol levels above 9°GL. Furthermore, there is a tendency of an optimum temperature at 30°C.

The fermentation yield is reported in Table 2. The mean score was 85% and the results reinforce that a temperature of 30°C is promising.

**Table 2—Fermentation yield by sub-products method.**

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Fermentation yields (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>84.02</td>
</tr>
<tr>
<td>30</td>
<td>86.79</td>
</tr>
<tr>
<td>32</td>
<td>85.05</td>
</tr>
</tbody>
</table>

These results indicate it is feasible to reduce the generation of vinasse with the fermentation of concentrated must and obtain alcohol levels above 8°GL. For example, for 9°GL the generation of the vinasse is 9 L / L ethanol and for 13°GL generation of vinasse is 6 L / L ethanol, i.e., there is a reduction of 33%.

**Must from syrup**

Since the best result was previously controlled temperature at 30°C, the tests were conducted with syrup at this temperature in order to produce wines with alcohol levels above 14°GL. Figure 7 shows the result of the fed batch prepared with syrup at 28% of total reducing sugar concentration in average and temperature controlled at 30°C. The average percentage of ethanol is 13.82°GL and the average standard deviation is 0.7%.
Figure 8 shows the result of the fed batch prepared with syrup at 35% of total reducing sugar concentration in average and temperature controlled at 30°C. The average percentage of ethanol is 15.45°GL and the average standard deviation is 1.2%.

Fermentation with high quality must enables the production of average alcohol content up to 15°GL, unlike wine from molasses. So, it can be inferred that the salts present in molasses limit the very high fermentation.

The parameter temperature should be evaluated under these conditions because it is not possible to infer the ideal temperature from these results.

**Conclusions**

According to the results obtained, we can conclude that:

- The operation of the pilot plant in the 2008/09 season was succeeded well, and the results obtained at low temperatures are very promising for very high gravity fermentation;
The increased wine in alcohol is directly related to the quality of raw materials;

The lithium-bromide absorption chiller worked effectively, and one can conclude
that it is a proven product for ethanol production applications;

The results of fermentation with molasses indicate that there is an optimum
temperature at 30°C.

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FERMENTATION ALCOOLIQUE AU MOYEN D’UN REFRIGIRATEUR
D'ABSORPTION ECOLOGIQUE A TEMPERATURE CONTROLEE–EcoChill

Par

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MOTS-CLÉS: Fermentation Alcoolique,
Température, Ethanol, Réfrigirateur d’Absorption.

Résumé

C’EST DANS le procédé de fermentation dans la production d'éthanol que se trouve le moins
d'efficience et les peres les plus élevées. Un des paramètres d’opération pour maximiser la
production d'éthanol est le contrôle de la température de fermentation qui doit être maintenue au
niveau optimal. Généralement, les systèmes de refroidissement sont constitués des refroidisseurs
par évaporation par lesquels la température la moins élevée qui peut être atteinte, est une fonction
de la température de bulbe humide. Ainsi, dans les pays tropicaux comme le Brésil, la température
de fermentation atteint normalement des valeurs supérieures à 32°C et peut même atteindre 36°C
dans les périodes chaudes. Cette condition a un effet négatif sur le métabolisme cellulaire en
réduisant la productivité d’éthanol et tout en nuisant à la viabilité des cellules. Pour déterminer les
paramètres d’ingénierie nécessaires à l’optimisation du procédé de fermentation pour la production
d’éthanol dans la conception des ensembles industriels, Dedini S/A a construit et installé une unité
de démonstration semi-industrielle dans une usine à sucre associée à une unité d'éthanol du groupe
Cosan. Le paramètre principal des expérimentations était le contrôle de la température de fermentation, qui variait de 28º–32ºC, en fonction de l'augmentation du contenu d'éthanol et l'influence des matières premières pour le rendement de fermentation. Les résultats obtenus démontrent qu'il y avait une augmentation significative de la concentration d'alcool dans le moût fermenté qui atteint 16° GL à 29ºC. Ainsi l’augmentation de la concentration en éthanol entraîne une réduction de la demande en vapeur requise pour la distillation et une réduction énorme en volume de vinasse générée. La température basse du moût fermenté mène à un niveau faible de contaminants, assurant ainsi une bonne qualité et un rendement supérieur en fermentation. Le réfrigérateur d'absorption à base de bromure de lithium fonctionne efficacement, donnant ainsi la preuve qu'il s'agit d'un produit éprouvé pour être utilisé dans la production d'éthanol.

FERMENTACIÓN ALCOHÓLICA CON TEMPERATURA CONTROLADA POR ENFRIADORES ECOLÓGICOS DE ABSORCIÓN—ECO CHILL

Por

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Palabras clave: Fermentación Alcohólica, Temperatura, Etanol, Enfriador de Absorción.

Resumen

El proceso de fermentación en la producción de etanol es donde puede encontrarse menos eficiencia y mayores pérdidas. Uno de los parámetros operacionales que maximiza la producción de etanol es el control de la temperatura de fermentación para mantenerla en el valor óptimo. Usualmente los sistemas de enfriamiento están constituidos por enfriadores evaporativos, en los que la temperatura más baja que puede alcanzarse es función de la temperatura de bulbo húmedo. Así en países tropicales como Brasil, la temperatura en la fermentación alcanza normalmente valores superiores a 32º C y puede elevarse hasta 36º C en períodos calurosos. Esta situación tiene un efecto negativo sobre el metabolismo celular reduciendo la productividad de etanol y dañando la viabilidad celular. Para determinar los parámetros ingenieriles para optimizar el proceso de fermentación de etanol en los diseños a escala industrial Dedini S/A construyó e instaló una planta demostrativa semi-industrial en una fábrica de azúcar-etanol del grupo COSAN. El parámetro principal de los experimentos fue el control de la temperatura de fermentación, que osciló entre 28 C y 32ºc, como una función del incremento del contenido de etanol y la influencia de la alimentación sobre el rendimiento de fermentación. Los resultados obtenidos muestran que se alcanzo un significativo incremento en el contenido de alcohol en el vino fermentado, que se elevó a cerca de 16º GL a 29º C. Resultando que el aumento de la concentración de etanol condujo a una disminución en la demanda de vapor para la destilación y una gran reducción en el volumen de vinaza generado, La baja temperatura del vino fermentado indujo una disminución de contaminantes, asegurando buena calidad y mayor rendimiento de fermentación. El enfriador de absorción de Bromuro de Litio operó con efectividad, indicando que es un producto probado para ser empleado en la producción de etanol.
HIGH PRESSURE MULTI FUEL FIRED
BOILERS FOR CO-GENERATION

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KEYWORDS: High Pressure Bagasse Boilers,
Efficient Thermodynamic Cycles, Important Mechanical Features.

Abstract
AN EVER widening gap between power generation and its growing demand, as well as
the problems concerning the steady decline of non renewable energy resources, has
been a major cause of worry, not just for India but for many countries around the world.
Depletion of fossil fuels, environmental concerns and the opportunities presented for
carbon trading between developed and developing countries under the Kyoto Protocol
have added to the importance of Green Power. The cane sugar factories, which have
been generating power only for captive use by burning bagasse during the crushing
season, have taken this as an opportunity to strengthen their revenue stream by
producing power on a year round basis and trading in carbon credits. This has been
achieved by adopting more efficient power cycles using high pressure and high
temperature boilers along with high pressure feed water heaters and extraction cum
condensing steam turbines. This paper reviews the advantages of using high pressure
co-generation boilers in the sugar industries with higher power output, improved cycle
heat rate and lower bagasse consumption. The multi-fuel firing capacity in the boilers
enables the power plant to operate on alternative fuels during the off-season when the
bagasse is fully consumed. The high pressure co-generation boilers thus ensure year
round operation with high availability. The paper also discusses the unique features of
high pressure boilers for ensuring high uptime, enhanced life, ease of operation and
maintenance, high efficiency, low power consumption and environment friendliness.
Salient performance data of one of the operating high pressure boilers is also
highlighted in Table 4.

Introduction
Traditionally, sugar mills have been using low pressure boilers (32 kg/cm²a, 45 kg/cm²a) for
generating power and steam for process. In order to make the plant cycles more efficient, the trend
in the sugar industries worldwide is gradually moving towards higher pressure and temperature
cycles along with multi-fuel firing capability in the boilers in order to maximise generation of
power from the available bagasse. This results in increased power generation during the crushing
season with savings in bagasse, hence keeping the power plant operational beyond the crushing
season. The plant operates on alternative fuel during the rest of the period, when bagasse is fully
consumed.

The advantages of using high pressure boilers for co-generation can be seen in Table 1.
With high pressure and temperature cycles, the benefits are as follows:
1. Higher power generation per tonne of bagasse.

It is also clear from this table that keeping the pressure constant and increasing the steam
temperature is not advantageous due to higher fuel consumption and drop in steam/fuel ratio.
Table 1—Advantages of a high pressure boiler.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Unit</th>
<th>45 kg/cm² (a)</th>
<th>66 kg/cm² (a)</th>
<th>87 kg/cm² (a)</th>
<th>105 kg/cm² (a)/540ºC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>440ºC</td>
<td>515ºC</td>
<td>485ºC</td>
<td>515ºC</td>
<td>515ºC</td>
</tr>
<tr>
<td>Feed water temp. to boiler</td>
<td>ºC</td>
<td>105(without HP heater)</td>
<td>150( with 1 HP heater)</td>
<td>170 ( with 1 HP heater)</td>
<td>220 (with 2 HP heaters)</td>
</tr>
<tr>
<td>Bagasse quantity</td>
<td>TPH</td>
<td>43.51</td>
<td>46.18</td>
<td>41.78</td>
<td>42.89</td>
</tr>
<tr>
<td>Steam/fuel ratio</td>
<td>–</td>
<td>2.29</td>
<td>2.16</td>
<td>2.39</td>
<td>2.33</td>
</tr>
<tr>
<td>Gross power output</td>
<td>MW</td>
<td>22</td>
<td>25.2</td>
<td>23.4</td>
<td>25.3</td>
</tr>
<tr>
<td>Net power output</td>
<td>MW</td>
<td>24.8</td>
<td>28.8</td>
<td>26.5</td>
<td>28.9</td>
</tr>
<tr>
<td>Specific steam consumption</td>
<td>kg/kW–h</td>
<td>4.03</td>
<td>3.46</td>
<td>3.77</td>
<td>3.46</td>
</tr>
<tr>
<td>Power generation per ton of bagasse</td>
<td>kw/Tonne Base</td>
<td>+9.5%</td>
<td>+ 11.4%</td>
<td>+18.3%</td>
<td>+ 21.4%</td>
</tr>
<tr>
<td>Heat rate</td>
<td>kcals/kW–h-h</td>
<td>3983</td>
<td>3640</td>
<td>3579</td>
<td>3370</td>
</tr>
</tbody>
</table>

Development of high pressure co-generation boilers

High pressure and high temperature cycles are important for increasing the operating efficiency and power output from co-generation plants. The choice of pressure and temperature levels for the steam cycle depends on several factors including fuel and ash properties, quality of feed water and water treatment systems available, cost of boiler and steam turbine systems and the level of confidence of plant operators.

Thermodynamically, the energy recovery from the Rankine cycle depends more on steam temperature than pressure. The cycle efficiency will increase with higher steam temperature. However, because of the nature of the working medium, pressure also plays a major role in ensuring optimum extraction of useful energy from the working medium as the enthalpy changes with pressure. Hence, an increase in steam temperature should be accompanied by a matching increase in steam pressure. The temperature selection is decided by the metallurgy of boiler pressure parts, piping, turbine components and the creep-fatigue behaviour of materials at higher temperature. For temperatures up to 400ºC, carbon steel material (SA 210 Gr A1/SA 210 GrC) is used for the heating surfaces. Alloy steel material (SA 213 T11, SA 213 T22) is used for temperature up to 520ºC. For higher temperature (540/545ºC), special alloy steel material (SA 213 T91) is used for the heating surfaces.

Having gained wide experience with operation of 66 kg/cm²(a), 485ºC cycle, the Indian sugar industry graduated to the next higher cycle using 87 kg/cm²(a), 515ºC cycle. Several co-generation boilers using this pressure cycle are successfully operating in India. The current trend is for still higher pressure operation at 105/110 kg/cm²(a) and 540ºC. Three units using this pressure cycle have been in operation for the past two years. Many more units using 110 kg/cm²(a) pressure are currently under execution.

The concept of regenerative feed water heating was introduced in the co-generation cycles to improve cycle efficiency. High pressure feed water heaters using bleed steam from the turbine have become a standard feature in all co-generation plants. The 66/87 kg/cm²(a) cycle uses one high pressure feed water heater to increase the feed water temperature to around 170ºC before entering the economiser. The 105/110 kg/cm²(a) cycle uses two stages of high pressure heaters to raise the feed water temperature to around 220ºC before entering the economiser. Regenerative feed water heating reduces the heat input to the boiler, thus optimising fuel consumption and increasing steam/fuel ratio.
The significant advantages of using a high pressure boiler in co-generation are:

- Saving in bagasse, hence extended period of operation.
- Higher power generation per tonne of bagasse.
- Lower fuel and steam consumption for the same power output, hence reduced boiler size.
- Improved heat rate, hence better cycle efficiency of the plant.

While efforts are being made to increase power generation by adopting higher pressure cycles, energy conservation efforts are also being introduced for optimising auxiliary power consumption and increasing the exportable surplus power to the grid.

Variable frequency drives are being extensively used to bring down the auxiliary power consumption. Boilers are designed with multi-fuel firing capability so as to ensure year round operation of the plant.

One of the major considerations for high pressure operation is the quality of feed water, boiler water and steam. Total solids and silica are required to be maintained at low levels in drum water at high pressures to maintain desired steam quality. Silica, in particular, is carried over in the form of vapour at high pressures and, hence, the silica content in feed water needs to be maintained at a very low level. Feed water is used for attemperation in the superheater system and any contamination in the feed water will enter the superheater circuit. This necessitates high purity for make-up water. Hence demineralisation and volatile treatments become necessary and the boiler water quality control becomes critical to minimise steam impurities to prevent deposits in tubes and turbine blades. Demineralisation can produce the acceptable make-up water quality with specific electrical conductivity less than 0.5 µs/cm with hardness completely removed and silica less than 0.02 ppm. Demineralisation of boiler feed water prevents failures due to deposits, ductile gouging, hydrogen embrittlement and corrosion.

The recommended feed water and boiler water quality is shown in Table 2 and Table 3 respectively. Salient performance data of one of the operating high pressure boilers is also highlighted in Table 4.

### Table 2—Recommended feed water quality.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Unit</th>
<th>45 kg/cm²(a)</th>
<th>66 kg/cm²(a)</th>
<th>87 kg/cm²(a)</th>
<th>105 kg/cm²(a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td></td>
<td>8.8–9.2</td>
<td>8.8–9.2</td>
<td>8.8–9.2</td>
<td>8.8–9.2</td>
</tr>
<tr>
<td>Hardness</td>
<td>ppm</td>
<td>Nil</td>
<td>Nil</td>
<td>Nil</td>
<td>Nil</td>
</tr>
<tr>
<td>Specific electrical conductivity after cation exchanger</td>
<td>µs/cm</td>
<td>2.0</td>
<td>0.5</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>Dissolved oxygen</td>
<td>ppm</td>
<td>0.20</td>
<td>0.007</td>
<td>0.007</td>
<td>0.005</td>
</tr>
<tr>
<td>Total dissolved solids</td>
<td>ppm</td>
<td>1.0</td>
<td>0.25</td>
<td>0.25</td>
<td>0.15</td>
</tr>
<tr>
<td>Silica</td>
<td>ppm</td>
<td>1.0</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Total iron</td>
<td>ppm</td>
<td>0.05</td>
<td>0.01</td>
<td>0.01</td>
<td>0.005</td>
</tr>
<tr>
<td>Total copper</td>
<td>ppm</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.005</td>
</tr>
</tbody>
</table>

### Table 3—Recommended boiler water quality.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Unit</th>
<th>45 kg/cm²(a)</th>
<th>66 kg/cm²(a)</th>
<th>87 kg/cm²(a)</th>
<th>105 kg/cm²(a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td></td>
<td>9.8–10.2</td>
<td>9.0–10.0</td>
<td>9.0–10.0</td>
<td>9.0–10.0</td>
</tr>
<tr>
<td>Total dissolved solids</td>
<td>ppm</td>
<td>150</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Specific electrical conductivity</td>
<td>µs/cm</td>
<td>300</td>
<td>200</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Silica</td>
<td>ppm</td>
<td>10</td>
<td>5 *</td>
<td>2.5 *</td>
<td>1.5 *</td>
</tr>
<tr>
<td>Residual phosphate</td>
<td>ppm</td>
<td>15–25</td>
<td>5–20</td>
<td>5–20</td>
<td>5–20</td>
</tr>
</tbody>
</table>

* To be controlled based on drum operating pressure so as to maintain silica less than 0.02 ppm in the steam leaving the boiler drum.
Table 4—Boiler performance.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Unit</th>
<th>87 kg/cm²(a), 515ºc</th>
<th>105 kg/cm²(a), 540ºc</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Designed values</td>
<td>Achieved values</td>
<td>Designed values</td>
</tr>
<tr>
<td>Plant</td>
<td>Nizam Deccan Sugars, India</td>
<td>Dhampur Sugars, India</td>
<td></td>
</tr>
<tr>
<td>Steam flow at main steam stop valve</td>
<td>tph</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>Steam temperature at main steam stop valve</td>
<td>Deg.C</td>
<td>515 ± 5</td>
<td>515</td>
</tr>
<tr>
<td>Steam pressure at main steam stop valve</td>
<td>kg/cm²(a)</td>
<td>87</td>
<td>87.2</td>
</tr>
<tr>
<td>Feed water temperature at economiser inlet</td>
<td>Deg.C</td>
<td>170</td>
<td>168</td>
</tr>
<tr>
<td>Back end temperature</td>
<td>Deg.C</td>
<td>150</td>
<td>148</td>
</tr>
<tr>
<td>Boiler efficiency on GCV basis</td>
<td>%</td>
<td>71.5</td>
<td>72.7</td>
</tr>
<tr>
<td>Auxiliary power consumption</td>
<td>kW</td>
<td>1096</td>
<td>1025</td>
</tr>
<tr>
<td>Particulate emission at ESP outlet</td>
<td>mg/Nm³</td>
<td>115</td>
<td>115</td>
</tr>
<tr>
<td>Noise level of rotating equipment at one metre distance</td>
<td>dB</td>
<td>85</td>
<td>&lt; 85</td>
</tr>
</tbody>
</table>

Features of high pressure boilers

For developing a boiler for cogeneration and suitable for generating power on a sustainable basis the following points are important:

1. Need for multi fuel firing.
2. Ability to give trouble free service throughout the year.

Of the several technologies available, the Travelling Grate boiler can burn bagasse as well as a variety of biomass fuels and agro wastes including rice husk, wood chips, and cotton stalk, besides fossil fuels like coal, lignite, oil and gas during the off season. Examples are shown in Figures 1, 2 and 3.

Fig. 1—Travelling grate boiler with boiler bank. Source: ISGEC John Thompson.
Fig. 2—Single drum design travelling grate boiler with evaporator pass.

Fig. 3—Single drum design travelling grate boiler with evaporator bank.
For robust and reliable operation on a year round basis, the high pressure co-generation Travelling Grate boiler needs to have the following essential features.

- High uptime
- High efficiency
- Low power consumption
- Environment friendly
- Low O & M cost

The specific design and construction features that IJT has incorporated in their Travelling Grate boilers are:

**High boiler uptime**

1. Stoker of rugged construction using heat resistant grate bars of Spheroidal Graphite iron metallurgy and chains made of hardened and tempered steel, cross beams and skid bars made of heavy sections and heat resistant material.
2. Pressure part tubes of seamless construction
4. Optimum flue gas velocities across heating surfaces to minimise erosion.
5. Furnace made of water cooled membrane wall construction to ensure gas tightness and minimum use of refractory to avoid maintenance.
6. Use of SA 213 T91 material for final elements of secondary superheater for high creep, fatigue and corrosion resistance.
7. Convective superheaters with wide pitching to avoid fouling due to alkali content in ash.
8. Double casing arrangement for economiser to protect bends from erosion.
9. Use of corten steel tubes in cold end section of tubular airheater to avoid corrosion.
10. Use of ferrules for airheater inlet tubes to avoid erosion.
11. Use of pre-dust collector at economiser outlet to reduce particulate loading on ESP; this avoids larger unburnt carbon carry over to ESP and hence eliminates fire hazards.
12. Stoker shaft provided with self lubricated graphite bearings ensures high reliability, minimum maintenance.
13. Refractory band provided at lower furnace zone above the grate to sustain combustion even with high moisture in bagasse.
14. Single drum design for high pressure (> 100 kg/cm²a) boilers. High ligament efficiency of drum (85–90%), lower drum thickness, no tube expansion and better circulation due to non-heated downcomers.
15. Tall furnace, generous volumetric loading ensures adequate residence time for fuel, hence reduces unburnt carbon loss.
16. On-line vibration monitoring system provided for critical rotating equipment ensures predictive maintenance and avoids failures.
17. On-line steam and water analyser system ensures strict control of water chemistry.
18. Automated operation with Distributed Control System with supervisory controls and data acquisition for accurate control with less manpower.

**High efficiency**

a) Generous sizing of furnace (conservative grate area and furnace volumetric loading) for efficient combustion of fuel.
b) Good secondary air distribution using high pressure air jets to ensure better turbulence and mixing due to staggered arrangement for efficient combustion of fuel.

c) Heat recovery through economiser and airheater for lower back and temperature.

d) Optimum excess air levels to reduce dry flue gas loss.

e) Refiring of grit and cinder for lower unburnt carbon loss.

f) Use of high pressure feed water heaters for fuel economy.

g) Use of variable frequency drive for feeders to regulate fuel feed.

**Low power consumption**

a) Use of low flue gas velocity across heating surfaces to reduce draft loss in gas path.

b) Use of variable frequency drives for fans and boiler feed pumps.

**Environment friendly**

a) Use of Electrostatic Precipitators to limit particulate emission to 30–50 mg/Nm³. Electrostatic Precipitators also have low flue draft loss (25–30 mm WC).

b) Use of closed dense phase system for fly ash disposal.

c) Use of efficient silencers to meet occupational Health and Safety Administration (OSHA) norms.

**Low O & M cost**

a) Automated operation, hence less manpower.

b) On line monitoring of condensate and boiler feed water quality using Steam and Water Analyser System (SWAS) prevents scaling and corrosion in boiler tubes, hence avoiding tube failures and ensuring high boiler availability.

c) Seamless steel tubes for boiler pressure parts, eliminates tube leakages, ensures high boiler availability with minimum maintenance.

d) Alloy steel tubes for superheaters, corten steel material for cold end of airheater provides resistance to corrosion, fatigue and ensures high boiler availability.

e) Replaceable wear liners for ID fan blades ensures resistance to erosion.

f) Use of soot blowers at strategic location for efficient on-load cleaning of heating surfaces hence avoiding fouling and bridging of ash particles in the heating surfaces.

g) Use of air bypass arrangement for the air preheater to avoid cold end corrosion during boiler start up, part load operation and also during low ambient air temperature conditions to ensure high boiler availability.

**Specific design and construction features of high pressure boilers**

- Rotary single drum feeder/Three drum feeder/Chain feeder for bagasse with pneumatic spreaders.
- Drag chain feeder for coal with mechanical/pneumatic spreaders.
- Three stage feed water heating (deaerator and two stages of HP heaters).
- Spray-cum-Tray type deaerator to achieve low dissolved oxygen (< 0.007 ppm) in boiler feed water.
- Convective superheater arrangement (shielded by nose) with interstage attemperator).
- Use of drum coil heaters for minimising cold end corrosion in economiser due to sulfur in fuel.
- Use of steam coil air preheater for minimising cold end corrosion in air heater during very low ambient air temperature.
- Conservatively designed steam drum to enable boiler operation with rapid load swings and fast response to load changes.
• Efficient drum internals consisting of cyclone separators, demisters to ensure high steam purity at all loads.
• Self lubricated graphite bearings (Morganite bearings) provided for stoker shaft. The morganite carbon bearing is chemically inert, dimensionally stable, non hygroscopic and highly resistant to wear.
• Drum internals of bolted construction for easy replacement/removal
• Temperature elements are provided on the Travelling Grate skid bar, cross beam and riddling hoppers with temperature indication in the control room.
• Minimum use of refractory in the boiler, thereby eliminating cumbersome maintenance.

Conclusion

With the rapid industrial growth over the last few decades, the demand for electrical energy has been growing at a tremendous pace. The application of the clean development mechanism (CDM) of the Kyoto protocol which gives monetary value to CO₂ emission reduction has become an important financial driver for biomass based co-generation.

Due to concerns related to cost and to bring about a reduction in emission of air pollutants and greenhouse gases, owners of industrial and commercial facilities are actively looking for ways to produce energy more efficiently. The incentive of trading carbon credits has become a motivation for considering the co-generation route. India has no doubt emerged as one of the leaders in co-generation.

The sugar industry in India has made phenomenal progress in co-generation particularly since bagasse, a waste product from sugar mills, is available at almost no cost as fuel. However, as bagasse is a seasonal fuel, there is a need to find other biomass fuels for year round generation of power. This has led to the development of multi-fuel fired boilers using high pressure and high temperature cycles which are crucial for increasing operating efficiency and power output from co-generation plants.

The additional power generation is a source of revenue for the sugar plant with opportunities to generate more income through trading of carbon credits.

CHAUDIERES A HAUTE PRESSION ET A MULTIPLE COMBUSTIBLES POUR LA COGÉNÉRATION

Par

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MOTS-CLÉS: Chaudières Bagasses De Cannes à Sucre à Haute Pression, Cycles Themodynamic Efficace, Importantes Caractéristiques Mécaniques.

Résumé

UN FOSSÉ toujours grandissant entre la production d'électricité et de sa demande croissante, ainsi que les problèmes relatifs à la diminution constante des ressources énergétiques non renouvelables, a été une des causes d'inquiétude majeure, non seulement pour l'Inde, mais aussi pour de nombreux pays à travers le monde. L’épuisement des combustibles fossiles, les préoccupations environnementales et les opportunités présentées pour les échanges de carbone entre pays développés et ce en voie de développement dans le cadre du protocole de Kyoto ont donné davantage d’importance à l'énergie verte. Les usines de canne à sucre, qui ont été génératrices de
puissance uniquement pour leur usage interne par combustion de bagasse de canne pendant la saison de broyage, ont saisi cette opportunité pour augmenter leurs revenus en produisant de l’énergie toute l'année et à travers la négociation des crédits de carbone. Cet objectif a été atteint par l'adoption des cycles d'alimentation plus efficaces à l'aide de chaudières à haute pression et à haute température associées à des systèmes d’alimentation d’eau à forte pression et des turbines à vapeur d’extraction cum condensation. Cette communication présente les avantages de l'utilisation de chaudières de cogénération de haute pression dans les industries sucrières avec une augmentation de puissance générée, une amélioration du taux de transfert de chaleur et une diminution dans la consommation de bagasse de canne. La capacité des chaudières à utiliser différents types de combustibles pendant la période d’inter-récolte quand la bagasse n’est plus disponible, permet à la centrale électrique de fonctionner pendant toute l’année. Les chaudières de cogénération à haute pression assurent ainsi le fonctionnement pendant toute l'année avec un haut degré de disponibilité. La communication comprend également des fonctionnalités uniques des chaudières à haute pression pour assurer une meilleure disponibilité, une durée de vie accrue, une facilité d’opération et d'entretien, une meilleure efficacité, une faible consommation et le respect de l'environnement. Les données saillantes de la performance d’une chaudière à haute pression en phase d’opération sont également mises en évidence au tableau 4.

CALDERAS DE ALTA PRESIÓN MULTICOMBUSTIBLES PARA LA COGENERACIÓN

Por

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PALABRAS CLAVE: Calderas de Bagazo de Alta Presión, Ciclos Termodinámicos Eficientes, Factores Mecánicos Importantes.

Resumen

UNA BRECHA permanentemente creciente entre la generación de energía y la ampliación de su demanda, así como el problema relativo al sostenido decrecimiento de las fuentes de energía no-renovables, ha resultado causa de la mayor preocupación no solo para la India sino también para muchos países del mundo. Depresión de los combustibles fósiles, alarma ambiental y las oportunidades que presentó el comercio de carbono entre los países desarrollados y en desarrollo bajo el Protocolo de Kyoto, han contribuido a añadir importancia a la Energía Verde. Las fábricas de azúcar de caña que han generado energía solamente para un uso cautivo por las fábricas de azúcar de caña que han generado energía solamente para un uso cautivo durante el periodo de producción azucarera, han tomado esto como una oportunidad para fortalecer corrientes de ingresos por la vía de producir energía todo el año y negociando en créditos de carbono. Esto se ha alcanzado adoptando ciclos energéticos más eficientes, empleando calderas de alta presión y temperatura, junto a calentadores de alta presión de alimentación y turbinas de extracción-condensación. Este artículo revisa las ventajas de emplear calderas de alta presión para cogeneración en la industria azucarera con mayores producciones de energía, ciclos con relaciones de calor mejorados y menores consumos de bagazo. La capacidad de las calderas de quemar varios combustibles permiten a las plantas de energía operar en el periodo de no producción azucarera con combustibles alternativos una vez consumido todo el bagazo. Las calderas de alta presión para cogeneración aseguran, así, una operación todo el año con alta disponibilidad. El artículo discute también, la propiedad única de las calderas de alta presión para asegurar elevada operacionalidad, larga vida útil, facilidad de operación y mantenimiento, alta eficiencia, bajo consumo energético y ser eco-amigables. En la tabla 4, se destacan las cifras de desempeño de una caldera de alta presión en operación.
REPORT: ISSCT COPRODUCTS WORKSHOP 2009

By

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KEYWORDS: Cogeneration, Boilers, Bagasse and Trash Handling,
Cellulosic Ethanol, Vinasse, Biocomposting, Biofermentation, Molasses.

Abstract

The ISSCT Coproducts Workshop 2009 was held in Coimbatore, India from 15-19 March 2009 and attracted 41 participants from 8 countries. There were two main themes: Monday was termed the ‘Energy day’ and dealt with liquid and solid energy production from coproducts, as well as cogeneration of electrical power from bagasse and cane trash. Very good audience participation and lively debate was prevalent. On Tuesday, 2 sugar mills were visited (Sakhti Sugars and Bannari Aman), which had high pressure boilers. Sakhti Sugars also has equipment for vinasse concentration and incineration, while Bannari Aman has a plant for biocomposting of vinasse mixed with filter cake. Wednesday was the ‘Derivatives day’ where issues such as Biofermentation of sugar into high-value chemicals, pulp and paper production from bagasse and addition of molasses to animal feed were debated in a smaller circle. On Thursday we visited an impressive printing and industrial paper production plant (SPB) and an adjacent sugar factory (Ponni Sugars) that provides bagasse for the paper plant as well as a very efficient common treatment of waste water. The Workshop was hosted and graciously sponsored by Ponni Sugars (Erode) Ltd. as well as by SPB – Seshaysee Paper and Boards Ltd. Erode. All papers were well presented and generated discussion and interaction among the participants. The main conclusions of the Workshop were: In view of the necessity to reduce greenhouse gas emissions, the importance of cogeneration from bagasse and other biomass as well as the production of bioethanol from molasses and cane juice will continue to increase; High pressure boilers and efficient power generation cycles (110 bar, 540°C) are well established and investment costs are coming down; Practical alternatives to deal with the large volumes of vinasse arising during the production of bioethanol are available, but optimisation of the technologies and investment volumes is still required; To adequately cover promising subjects, the division into 2 sections (Energy and Derivatives) should be kept for future workshops. The actual emphasis on either one of these could vary according to the amount of contributions received. To encourage better participation for participants with limited time, there should be 2 days of consecutive presentation sessions followed by 2 days of plant visits for the next workshop. Many papers were considered suitable for submitting to the ISSCT Congress in Mexico in March 2010.
Introduction

The ISSCT Coproducts Workshop 2009 was held at the Residency Hotel, Coimbatore, Tamil Nadu (South India) from 16–19 March 2009 and was hosted by Ponni Sugars (Erode) Ltd. and SPB- Seshasayee Paper and Boards Ltd, who were in charge of the local organisation of the venue and site visits. The Sugar Technologists’ Association of India (STAI) helped generate interest amongst its members in attending the workshop.

The overall theme of the workshop was ‘After the Oil has gone: Utilisation of Sugar Cane Coproducts’. Two main theme blocks were chosen: Energy and Derivatives. The first two days of the workshop were dedicated to Energy related themes and plant visits, whereas the third and fourth days were dedicated to Derivatives and related plant visits.

The workshop was attended by 41 participants from 8 countries (30 from India and 11 from Australia, Germany, Mauritius, Reunion, Sweden, Thailand, Uganda and the United Kingdom). Some Coproducts Section Members and sugar technologists from Brazil and other Latin American countries, who had initially expressed interest, were prevented from participating due to the economic crisis.

Financial support as well as great personal input was provided by the top management of Ponni Sugars Ltd and SPB, without which this workshop would not have been possible. Hospitality at the three sugar mills visited (Sakhti Sugars, Bannari Aman and Ponni Sugars) and especially at the paper plant (SPB) was very warm and generous.

Technical sessions

Session A – Overview speeches

After the oil has gone: potential for coproducts of the cane sugar industry (P. Avram, IPRO Industrieprojekt GmbH, Braunschweig, Germany)

There is a wide range of coproducts available from sugarcane, respectively ‘downstream’ products derived from bagasse and molasses. Most of these, however, have not reached particular economic significance or are ‘niche products’ that have only a limited market. The two currently most economically significant coproducts are bagasse as a fuel and molasses for ethanol production.

Worldwide cogeneration potentials for bagasse-based cogeneration are about 100 kWh per tonne of cane export power from sugar mills. This figure is already being attained in the more efficient sugar factories in Brazil, Guatemala, Reunion, Mauritius, India, etc, where the price being paid for electrical power from sugar mills is economically attractive. If the major cane producing countries could fully realise this potential, the sugar mills could cover an average of 7.5% of their total national electricity demand.

The results of an earlier case study for a 20 000 t/d fully electrified sugar mill employing 65 bar steam boilers, condensing-extraction turbines and additionally dried bagasse show that 112 kWh/t can be sold to the grid. With higher pressure boilers (110 bar, 540°C) available today, this figure can be raised additionally by about 13% due to the higher thermodynamic cycle efficiency.

In recent years, fuel ethanol produced mostly from either sugarcane or corn (maize) has reached levels of over 40 ML annually and continues to rise. The worldwide cost situation of various biofuels shows that cane-based bioethanol in Brazil has an average production cost of €0.24 per litre, ethanol from corn in the US €0.42 per litre and gasoline costs wholesale an average of €0.54 per litre. The cost advantage of cane-based ethanol lies in its higher yield per ha (6000 L/ha vs. 3000 L/ha from corn) and easier conversion via direct fermentation of molasses from cane juice. Also the fossil energy balance of ethanol from sugarcane is approx 8:1, compared to only 1.5:1 for corn and 0.80:1 for gasoline from crude oil.
In the future, ethanol from cellulose crops appears to have great potential regarding an
even better fossil energy balance than ethanol from sugarcane. Also synthetic gasoline from
gasification of agricultural wastes / biomass has shown good potential but, in both cases,
production costs are still far from being competitive. The greenhouse gas emissions of these
alternatives appear to be somewhat better when considering all sources of greenhouse gases
 emitted during cultivation, transport and production / conversion.

An overview was also given of a very energy efficient beet-juice and syrup-based
ethanol plant designed by IPRO that went on stream in 2008 in Germany. By employing a
double-effect distillation scheme, the process steam demand has been reduced to 1.7 kg/L
anhydrous ethanol. Further, the residual vinasse is concentrated in a six-effect evaporation
plant to 60° Brix and sold as a fodder additive. The applied technologies can be easily
transferred to cane-juice or molasses-based distilleries.

Overview of the Indian Coproducts situation (R. Chandramouli, Ponni Sugars Ltd.,
Erode, India)

The sugar industry is the second largest agro-based industry (after Textiles) in India.
There are about 500 sugar mills operating, out of which 41% are in private hands and 59% are
cooperatives or belong to the public sector. Each mill employs directly 300–500 persons and
indirectly another 200–300 persons. Total annual cane production in the last 3 years has
exceeded 300 Mt. About 70% of this amount is processed in the sugar factories, while the
balance is employed for jaggery and handsari (artisan sugar) and for seed planting.

Total sugar production has reached 28.2 Mt in 2006–07 and 25.5 Mt in 2007–08. Per
capita consumption of sugar in India is 19–20 kg/annum with a current population of
1130 million. The area under sugarcane varies between 3.5 and 4.5 Mha, depending strongly
on the price paid to farmers and competition from other cash crops as well as on drought or
pest attacks.

The most important coproduct is bagasse, with an annual production of 60 to 75 Mt.
Its main use is for power and energy production in the sugar factories. Currently there is
installed electrical generation capacity of 1280 MW, from which 847 MW are exported to the
grid. Potentially up to 10 500 MW of power could be produced, out of which 6270 MW could
be additionally exported once all mills have high pressure boilers and fully electrified factory
drives. Sugarcane trash has also been recognised in India as a valuable source of additional
fuel, because of its much higher calorific value than bagasse. Several schemes of trash
utilisation in the boilers are being tested with good results.

A smaller user for excess bagasse is the pulp and paper industry. The overall demand
for paper in India is currently 6.6 Mt per annum and rising rapidly. Currently about 32% of
the raw material employed for pulp and paper making is agricultural wastes, out of which a
good part is bagasse. It is estimated that potentially 6–10 Mt of bagasse could be used by the
paper industry. The particle board industry is another smaller user for excess bagasse,
accounting for about 375 000 t per annum.

Final molasses production has varied between 8.5 and 13 Mt during the past 3 years.
Over 70% of this amount is diverted to alcohol distilleries. The balance is employed in oil
mills, cattle feed, poultry units and chemical derivatives. The total installed distillation
capacity in India is currently 2900 ML per annum, out of which 1300 ML are adjunct to sugar
mills. Of the total annual demand of 2069 ML, about 29% is ethanol for fuel blending, 37%
for potable uses and 34% for industrial uses. There is a severe shortage of ethanol for fuel
blending.

Filter cake with an annual production of 6.5 Mt is next in order of importance. Over
60% is employed for biocomposting (increasingly together with vinasse from alcohol
distillation) and the balance is sold to farmers as manure. Lastly, M. Chandramouli referred to the lift irrigation scheme devised at Ponni Sugars for jointly treating the waste water emanating from the adjacent SPB paper mill and employing it for irrigating the cane fields. Also, the treated waste water from the sugarcane process is recirculated, thus reducing the fresh water consumption for the process to zero.

**Greenhouse gas abatement policy initiatives (Dr Bryan Lavarack, Mackay Sugar Ltd., Queensland, Australia)**

Policies developed at an international scale to mitigate the effects of climate change were briefly reviewed. The Kyoto Protocol sets binding targets for 37 industrialised countries and the European community for reducing greenhouse gas emissions. A total of 186 parties of the Convention on Climate Change have ratified the Protocol to date. The targets amount to an average of 5% against 1990 levels over the 5-year period 2008–2012. The majority of the industrialised countries, i.e. the European Union and the UK, have established targets for 2020 of 20–32% reduction below 1990 levels. The new US Administration is proposing to achieve a per capita reduction of 25% below 1990 levels by 2020.

The allowed emissions are divided into ‘assigned amount units’. As per the Kyoto Protocol, a trading mechanism allows countries that have emission units to spare—emissions permitted to them but not used—to sell this excess capacity to countries that are over their targets. Emitter of greenhouse gases (industrial production units) need to acquire a permit for all greenhouse gases they emit. The number of permits issued by the Government in each year will be limited. Firms will compete to purchase the number of permits they require. The ones that value them most highly will pay more for them, either at auction or at a secondary trading market. For a number of firms it will be cheaper to reduce emissions than to buy permits. Therefore, the marketplace will help to reduce CO2-emissions on a global scale.

Most sugarcane producing countries are not liable to achieve this target for the short term since these countries are regarded as developing. The Government of Australia accepted the requirements for the Kyoto Protocol in December 2007 and has committed the country to achieving these targets. Under current accounting rules, carbon dioxide emissions from the combustion of biofuels and biomass are zero-rated, because these emissions are equivalent to carbon sequestering through growth of these feedstocks. Therefore a major opportunity is developing for sugarcane coproducts as biofuels and biomass.

**Session B – Liquid energy**

**Late technology in vinasse evaporation (C Stoffers, Alfa Laval, Sweden)**

This presentation reported on the lessons learned from concentrating vinasse up to 60% solids with plate heat transfer equipment. The properties of the vinasse, in particular propensity to scaling, raw material quality and treatment and viscosity all influence the design. Rising film plate evaporators are suitable for concentrating up to 40% solids. Forced circulation through plate heat exchangers with flashing in a separate vessel is required to achieve higher concentrations. A three effect system with thermal vapour recompression is suggested to achieve solids levels up to 60%. Some of the vapour from the first effect is recycled through thermal vapour recompression (TVR). An installation capable of concentrating up to 52% solids for a distillery in Colombia was reported during the presentation. The presentation noted that support fuel is required for boilers that are fired with the concentrated vinasse.

**Evaporation system for molasses-based distillery effluent: a successful leap towards zero discharge (S. Chaudhari, Praj Industries, India)**

This presentation described several options for processing the effluent from distilleries with close examination of the option for evaporation and incineration. The main concerns for
Evaporators concentrating spent wash (vinasse) are scaling, plugging, foaming and require CIP (clean-in-place). The design for CIP should focus on the cost of chemicals, shut-down frequency for cleaning and methods for disposal of spent cleaning chemicals. The concentration of solids in the spent wash is directly proportional to the viscosity which in turn is proportional to (i) higher capital costs requirement for additional heat transfer area and (ii) increased operating costs from higher power consumption in pumps because of higher pressure drops. The higher the requirement for solids in the concentrated spent wash (exiting the evaporators), the higher are the capital and operating costs.

Conventional falling film, forced falling film, forced circulation and fluidised bed types of evaporators are suggested as solutions for the evaporation of spent wash. A system has been designed for Bannari Amman in India. The evaporator station is designed to produce 58–60% solids for a distillery rated at 60 kL/d. The incineration boiler can provide all the requirements of high pressure steam for power generation and of exhaust steam for process heating in the distillery and evaporators. Other evaporator installations were briefly reported.

**Zero liquid discharge through spent wash incineration (R. Rajesh, Thermax Boilers, India)**

The policy of zero liquid discharge being implemented in India at present requires that ethanol plants adopt new technologies for effluent discharge. The production of bio-compost from filter mud and spent wash is not viable for new stand-alone distilleries and another solution is required. This presentation described the requirements for a boiler incinerating concentrated vinasse (spent wash) for Bannari Amman in India. Brief details of three similar boilers presently under construction are also given.

For the boiler at Bannari Amman, the firing rate of concentrated spent wash is 8.8 t/h and steam generation capacity is 23.4 t/h of which about 16.6 t/h is required for process heating. About 1.6 MW of power is generated. The incineration boiler can provide the entire needs for power and steam for the stand-alone distillery. The boiler is a fluidised bed design which requires concentrated vinasse at 55–60% solids and 10–15% support fuel. Coal is the support fuel in the application described. The boiler assembly is a gas tight design. Total combustion is ensured through adequate residence time in the combustion chamber.

The high alkali content in ash from incinerating concentrated spent wash fouls the heat transfer surfaces. This is minimised through multi-pass design and provision of mechanical rappers for soot removal. The presence of chlorides leads to high temperature corrosion of the superheater. The boiler is reported to have operated successfully for more than 45 days without cleaning.

**Vinasse as a fuel – practical results (Dr N. Schopf, Saacke, Germany)**

This presentation focussed on the application of burners to incinerate vinasse and similar materials. Two case studies are presented for factories incinerating vinasse-like material at Araucaria and Cambé, both in the Parana state of Brazil. Both boilers are 42 bar boilers with 40 t/h and 60 t/h steam capacities. The main design issues for the burners for these boilers are high ash content, low calorific value (resulting from high water content) and conditioning system required for atomisation of the fuel.

The design for the boiler requires a support fuel to bring the boiler up to temperature and to ensure the flame is stable in the burner. The requirements for the support fuel are low once the boiler is at temperature. Typical support fuels required are natural gas, heavy fuel oils and animal fats.

Detailed descriptions of the burners required for the boilers were given in the presentation. The typical characteristics of the feed materials and the combustion products were presented and comparisons between vinasse and the vinasse-like material were given.
Technology to reduce, re-use and recycle spent wash from ethanol production
(A. Vadanagekar, KBK Renuka, India)

This presentation described proprietary designs for ethanol plants in India, Thailand and Africa.

Reduction of low volumes of concentrated spent wash is achieved by recycling a certain proportion of spent wash to fermentation. A typical production value of 3 volumes of concentrated effluent per volume of ethanol (or 3:1) is claimed for the 160 kL/d ethanol plant at Athani, Karnataka State. The typical value for the industry in India is about 8:1. 12% alcohol concentration is being achieved in the fermenters. Excess spent wash is concentrated to 30% solids content and sent to biocomposting.

Developments in cellulosic ethanol – Australian perspective (B P Lavarack)

The main technologies to produce ethanol from bagasse and other cellulosic materials were reviewed in this presentation. The review only included information on major technological developments that have been published in the open literature. The two main pathways for the production of ethanol from bagasse were described; namely biochemical and thermochemical technologies. In the biochemical pathway, the DHR, Iogen, Lignol, Arkenol, Verenium and permutations of the technologies were discussed. The thermochemical pathway of gasification was reviewed and some recent developments in North America were described.

For cellulosic ethanol to be successful, it should be more competitive than existing ethanol production technologies based on starch (e.g. corn) or sugar (e.g. cane molasses) feedstocks. A target minimum selling price of US$1.07/US gal (at 2002 pricing) has been set by the USA Government agency (NREL) for the development of cellulosic ethanol. At time of presentation, it was apparent that cellulosic ethanol is not competitive, but this situation is changing rapidly, as the cost for the necessary enzymes has come down significantly in recent years.

Introduction to Sessions C and D

The Monday afternoon session was dedicated to solid fuels, recognising the direct energy value of sugarcane fibre: primarily bagasse but also trash. Economics dictated that most of the topics were commercial scale but there was some domestic scale as well.

Fundamentally, cane fibre has a bone dry GCV of almost 20 000 kJ/kg [not far from coal at perhaps 26 000], but it is a carbohydrate so has a higher wet gas loss than coal, more akin to gas or oil. The problems are that it is never bone dry – more like 50% moisture – it has an erosive ash content and it has a low bulk density plus difficult mechanical handling properties. It turned out that there were three natural divisions to the proceedings: solid fuels, trash utilisation and export cogeneration.

Solid fuels

Handling and storage of solid fuels) (Dr Bryan Lavarack, Mackay Sugar Ltd., Queensland, Australia)

The large scale storage of bagasse is essential for the more industrial uses of bagasse and it is its physical characteristics which dictate how this can be done: low bulk density; mat forming; high moisture content; subject to decomposition [and hence possible spontaneous combustion]; potential for environmental issues [dust, water run-off, odour]

Storage options range from low technology [and high use of mobile equipment] open piling through open air linear piling with units similar to wood chip pilers to high technology storage sheds which can be either circular [Australia] or linear [Southern Africa]. Several countries have also tried baling in one form or another but without too much success.
The solution adopted depends primarily on local conditions for operations but it will become more important in the future as nations seek to reduce greenhouse gas emissions. Innovative answers will be required which are safe, economic and environmentally friendly.

**Bagasse briquettes and pellets (Dr M.B. Inkson, TSE, UK)**

The low bulk density of bagasse [125 to 150 kg/m³] is a serious drawback to its use, except when it comes to suspension firing. Techniques are required to increase the density for large-scale transport and/or storage or to create a solid fuel for domestic or small-scale industrial use.

The issue is economics: the cost of plant and energy to compress the bagasse and again to decompress it. Low pressure baling to something closer to 1000 kg/m³ is, therefore, probably the answer, a technique which also reduces the oxygen content in the pile and reduces the fire risk of bagasse storage.

Pelletising [to make 8–15 mm extrusions] and briquetting [to make >50 mm extrusions] are techniques for making solid fuel. Typically they rely on the natural components of the biomass – waxes and the like – to bind the pellet or briquette. Unfortunately, bagasse is highly abrasive so the dies in the machines do not last long and are expensive to replace so that the economics at an industrial scale do not add up. There is also the issue of moisture: pre-drying is required and, if that was easy, it would be routine for all boiler fuel.

However, the desire for ‘green fuels’ is distorting economics and bagasse pellets are being made at industrial scale and shipped across oceans so maybe the future holds promise.

**Trash utilisation**

**Cane trash as boiler fuel (N.Prabhakar, Nava Bharat Sugar, India)**

Trash, up to 15–20% of the clean cane mass and with only about 30% moisture has about one quarter of the crop’s total energy content. There is the potential to produce an additional 730 kWh per tonne of trash – which would, if fully utilised, increase the industry’s power export by 87% in India and reduce the country’s annual energy deficit by 28%.

Another reason for investigating trash as a fuel is that, in India, at least, newer cane varieties have lower fibre contents. The average has decreased from 14 to 12.64% in this decade alone.

The higher cost of separate handling for trash and the impact of the high alkali metal content on the boiler led Nava Bharat to try whole-cane processing. The benefits were as expected with no serious impact on boiler operations, although bagasse moisture and ash contents were higher. There was a slight increase in cost of transportation and a reduction in sugar recovery due to pol loss through increased bagasse and juice purity.

**Cane field residues as boiler fuel (K N Nibe, Pandurang Sugar, India and D K Goel, STM, India)**

The very recent results of separate harvesting and burning trash at a mill in Maharashtra were reported.

Typically, 100 t of clean cane is harvested per hectare with green tops going for animal feed, leaving 8–10 t of trash. The trash is baled with commercially available units and delivered to the factory at a cost of US$16 per tonne. The trash has a GCV of almost 16 000 kJ/kg, two thirds more than that of the factory’s bagasse so the price is equivalent to about US$10/t.

The bales are shredded again in specially made, electrically driven units and fed to the boilers at a rate of about 5% of the bagasse feed rate. No adverse impact on the boiler operation has been observed in the first 60 days of the trial.
Export cogeneration

Overview of modern bagasse power stations (Dr M.B. Inkson, TSE, U.K.)

Export cogeneration involves a series of steps, each of which reduces the overall efficiency of the process. The boiler contributes the highest apparent loss but the hidden and sometimes highest loss lies in the overall time efficiency of the factory: those periods when not crushing and therefore not making boiler fuel but still consuming steam.

Over 90% of boiler losses are stack losses so boiler efficiency can be optimised by minimising excess air and the flue gas exit temperature. However, the first focus should be on minimising bagasse moisture in the factory [or by drying – a topic sadly missing from the workshop] as the greatest by far of the stack losses is the wet gas loss.

Although turbine efficiency is important to the work recovered [and hence the station’s export capability], it contributes little to energy loss as the un-recovered energy appears in the exhaust steam. It is worth noting, however, that the efficiency can be optimised by selecting high speed machines and considering twin shaft units if a lot of condensing is involved. Condensing, however, should be considered with care: cogeneration is more efficient than condensing and it is only the ‘free’ fuel that permits competition with a utility.

The HP steam condition is the final point for efficiency discussion: thermodynamics dictate that higher conditions deliver a higher efficiency. However, when economics are considered the return on investment at higher conditions seems to fall.

Experience with bagasse-based cogeneration (G.V. Raman, Avantgarde, India)

There has been a steady increase in HP steam conditions in India with several stations at or about 110 bar/540°C and now one at 125 bar/540°C, although how the two different pressures with one temperature can both be optimal was challenged. There is an 8% improvement in work recovered when going from 67 bar/485°C to 87 bar/515°C and another 7% in going from there to 110 bar/540°C. The capital cost increase from the lowest condition to the highest is 25%.

The most important points during conceptual design are to take the OTE (overall time efficiency) into account and to downsize the station to ensure a good load factor. Other factors presented also reinforced those made in the previous paper and then focused on the steam % cane ratio.

Mills in India are now achieving 36% steam % cane: a value which delivers 10.7% more electricity than 50% steam on cane on a gross basis. The point was also made that re-injecting medium pressure bleed from the turbine into the boiler, whilst counter-intuitive, is a valuable way of improving cycle efficiency.

On the turbine side, the issue of silica solubility in steam was highlighted which leads naturally to the need for considerable attention to be paid to boiler feedwater and boiler water qualities. Membrane technologies have mainly been adopted for water treatment in India and membrane costs have come down considerably.

Operating costs are more favourable than ion exchange technologies too, although they do start to converge at low raw water dissolved solids levels.

The final point addressed was the question of the station’s parasitic power. In the early 1990s, the parasitic power of a typical station was about 12% of gross. Ten years later it had dropped to about 8%, just by using VFDs instead of dampers and valves to control flows and pressures.

High pressure multi-fuel boilers (A.K. Subramanian, ISGEC John Thpmon, India)

This paper examined the features of a typical modern Indian boiler firing bagasse, other fibrous fuel and Indian coal. The HP conditions were 105 bar/540°C.
It is a single drum unit rather than bi-drum but otherwise much like similar boilers operating at lower conditions. It did, however, receive much hotter feedwater because of the two-stage BFW heating in the thermodynamic cycle. That is possible because of the higher saturation temperature at which the boiler operates.

The single drum can be much thinner walled as there are few penetrations and it also allows for non-heated downcomer tubes so circulation is improved. The separate steam generation bank eliminates tube expansion and the associated issues. The particular design adopted the so called flag concept with the tubes at the top of the heat recovery tower.

Higher HP conditions do require careful attention to be paid to materials of construction, as was evident in this boiler.

**Advanced bagasse boilers (E. Browne, Cethar Vessels, India)**

The paper also examined the features of a typical modern Indian boiler firing bagasse, this time generating at 107 bar/545°C. The unit, however, was a conventional bi-drum design.

This particular company is currently building the boiler for the highest HP conditions in India: 135 bar/545°C

**Power generation efficiency of Greenfield Sugar Plants (D K Goel, STM, India)**

This important paper compared the results from six Indian export cogeneration factories as being typical of 36 surveyed in total. Brief cycle characteristics were:

- A: 45 bar/430°C back pressure power cycle without HP heater.
- B: 45 bar/430°C extraction condensing power cycle without HP heater.
- C: 67 bar/500°C back pressure power cycle without HP heater.
- D: 87 bar/515°C back pressure power cycle without HP heater.
- E: 87 bar/515°C extraction condensing power cycle without HP heater.
- F: 87 bar/515°C extraction condensing power cycle with HP heater.

The survey confirmed that higher HP conditions and using the boiler as part of the cogeneration are both beneficial. The station efficiency of the six examples was presented as the net electrical export MW per MW available in the fuel bagasse expressed as percent:

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<th>Station efficiency</th>
<th>A</th>
<th>B</th>
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<td></td>
<td>9.00%</td>
<td>12.94%</td>
<td>12.30%</td>
<td>13.68%</td>
<td>14.58%</td>
<td>15.34%</td>
</tr>
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Extrapolating the data, an efficiency of 16% was predicted for a 110 bar/540°C cycle and, if bagasse drying is adopted, an efficiency of about 17% might be expected.

**Overview of high efficiency turbines (Dr M.B. Inkson, TSE, U.K.)**

Little has changed fundamentally with steam turbines since Parsons hit upon the need to have many small let-down stages rather than a single large stage over a century ago. Higher-speed machines are more efficient than low-speed ones, but speed is limited by the need to keep the tip speed below the speed of sound. Every single shaft multi-wheel turbine is therefore a compromise and efficiency suffers. As we move to more stages – and particularly extraction condensing machines – the problem gets worse.

The other issue is that a condensing section requires typically at least 10% of the steam flow to pass through the back-end in order to keep it cool.

One solution is to install more than one turbine, using a back-pressure machine during crop and a condensing machine during off crop operation: an expensive approach. A better solution is to have twin shaft machines [on the basis that triple or more shafts are uneconomic] with each shaft at an optimum speed. It might then be possible to decouple the condensing section during crop.
Overview on bagasse gasification (Dr B.P. Lavarack, Mackay Sugar Ltd. and Dr P.A. Hobson, Queensland University of Technology, Queensland, Australia)

Ultimately, though, the way to improve the efficiency of electricity production from bagasse is to adopt bagasse gasification coupled to a combined cycle station: a gas turbine followed by an HRSG (heat recovery steam generator) and steam turbine. A doubling of the gross electrical production can be expected.

There are many types of gasifiers with much work on-going. A search in 2007 identified 13 ‘credible’ technology suppliers using a range of technologies but none of them is yet able to offer anything over 5 MW-electrical and nothing has been achieved yet in the cane sugar industry. Of the work that has taken place in our industry, nothing has yet reached commercialisation and work seems to have more or less stopped for now.

Beyond gasification with combined cycle lies gasification to produce biofuels and hydrocarbons: essentially the Fischer Tropsch process. This lies still further in the future and it is unclear how it would be integrated into the sugar factory – one point which has at least been resolved with the combined cycle option.

Sessions E and F – Biofermentation of sugar into chemicals

Biofermentation of sugar into high value chemicals and polymers (Prof. D. Jhurry, University of Mauritius, Réduit)

This presentation discussed the option for Mauritius to produce products both from the sugar industry and the sea (the two main local resources available in the country). In particular they focus on (i) polymers for medicines and therapeutics, (ii) value added chemicals and (iii) green analytical procedures for quality control.

The concept of white biotechnology was explained: the application of nature’s toolset (yeasts, mould, enzymes and plants) to synthesise products that are easily degradable, require less energy and produce less waste. An interdisciplinary approach is required.

Examples of the fermentation of sugars into sugar alcohols were discussed. The potential for application as low calorie sweeteners is large.

Biobased polymers (Prof. D. Jhurry, University of Mauritius, Réduit)

Microbiological produced polymers manufactured include polysaccharides (xanthan gum and hyaluronic acid) and polyesters (polyhydroxbutrate (PHB), Natureworks™ and Sorona®). The advantages of these biobased polymers are (i) they use renewable resources and up to 55% less fossil resources, (ii) they contribute to reducing greenhouse gas emissions and (iii) require cheap biological feedstocks. The basics for the production of PHB (biodegradable plastic) were discussed, including fermentation and chemical recovery.

From sugar to lactic acid and polylactic acid (Prof. D. Jhurry, University of Mauritius, Réduit)

The potential for lactic acid as an intermediate chemical for conversion to both esters and polylactic acid was described. Lactic acid esters are used in cosmetics and in the food industry. Polylactic acid (PLA) is a polymer with applications in the packaging industry and in the medical field.

Preliminary results were presented for the production of lactic acid from mixed juice and syrup feedstocks using a Lactobacillus strain. The steps for the recovery and purification of lactic acid were given. CMR (Carbon 13 magnetic resonance spectroscopy) and NMR (nuclear magnetic resonance spectroscopy) results were presented that indicate that the process is technically feasible. The initial laboratory work will transfer to pilot plant scale.

Market opportunities exist in India for lactic acid as well as for other fermentation products including L-lysine, gluconic acid, itaconic acid and glutamic acid (MSG).
Session G – Pulp and Paper production

**Pulp and paper manufacture from sugarcane bagasse (K. Viswanathan, SPB-Seshasayee Paper & Boards Ltd, Erode, India)**

SPB (Seshasayee Paper and Boards Ltd.) and TNPL (Tamil Nadu Newsprint and Papers Ltd) produce over 120 000 and 200 000 tonnes, respectively, per year of newsprint, as well as printing and writing paper from bagasse and wood. SPB was established in 1960 and TNPL in 1992 and both have achieved high productivity and ecologically friendly production methods. While raw materials for paper worldwide consist of 57% wood, 39% waste paper and only 4% agro residues (i.e. bagasse and others), in India the proportions are 37% for wood as a raw material, 32% waste paper and 31% of agro wastes (mostly bagasse).

Agro fibres require only 50% of chemicals when compared to wood. About 5.5 t of bagasse are required for producing 1 t of bagasse chemical pulp. By adding a minimum necessary amount of wood pulp (10–15%), the paper mill produces approx. 1.17 t of printing and writing paper from 1 t of bagasse chemical pulp.

Bagasse as a fibre source for paper making has a number of advantages over other raw materials such as bamboo, soft or hard woods and wheat or rice straw:

- Lower alkyl-benzene extraction requirement (because of lower content of wax and resins)
- Higher pentosan content (good bonding characteristics)
- Lower lignin content and more open structure (easily pulpable with less chemicals)
- One disadvantage in relation to soft and hard woods is the higher 1% NaOH solubility, indicating potential deterioration during storage (this can be handled with adequate precautions)
- ith separated from the bagasse fibre is burnt in steam boilers, thus providing energy
- Lower tearing strength of bagasse pulp is due to short fibre length due to crushing in the sugar mill; this can be compensated by adding wood pulp with longer fibres

The presentation was complemented by a very well organised visit to the SPB plant and to the adjacent Ponni sugar mill.

**Production of bagasse-based particle boards in India (V.S. Raju, Ecoboard Industries Ltd, Pune, India )**

India produces annually about 200 000 m$^3$ of bagasse-based particle board in 17 plants located in Maharashtra, Gujarat and Uttar Pradesh. These particle boards are employed for furnishing office, school and household furniture with good appearance and better mechanical properties than wood-based particle boards, thus saving an equivalent felling of trees. India’s potential requirement of particle boards is assessed at 10 Mm$^3$ to meet increasing construction and housing activity; the same could be produced by establishing about 1000 similarly sized plants and by using pith-free fibre from bagasse produced by the existing 560 sugar mills and other agri-crop residues.

About 250 t of bagasse are required to produce 100 m$^3$ of particle board per day (typical size of the existing plants), respectively 3.5–4 t of sugar mill bagasse with 48% moisture are required to produce 1 t of particle boards.

Presently, however, bagasse is also in great demand for cogeneration purposes. Both uses contribute to the reduction of green-house emissions.
Session H – Animal feed and others

Addition of molasses to cattle feed (S. Ramamurthy, SKM Feeds, India)

Compounded cattle feed is a concentrated feed i.e., high in nutrient content. It does contain a maximum of 11% moisture, minimum of 60% total digestible nutrients (TDN) and not more than 18% crude fibre (CF). The main raw materials for the compounded dairy cattle feed are maize or corn, sorghum, broken rice and ragi. That apart, some deoiled rice bran, wheat bran, maize bran and rice polish are also used as ingredients. Additionally, certain oil cakes such as cottonseed extraction, coconut extraction, soybean extraction and Gingelly oil cake are also used.

Molasses is another major component which is used in cattle feed manufacture. It has the unique advantage of stimulating the rumen activity, improves appetite, increases forage and dry matter intake and enhances digestion. Molasses as a byproduct of sugar manufacture is more attractive so that forage intake can be increased and is economically viable. The other ingredients used are salt, calcite, dicalcium phosphate, mineral supplement, vitamin AD3 supplement, etc.

Sugar cane coproducts in Thailand (Dr P. Weerathaworm, Mitr-Phol Group, Thailand)

The Thai sugar industry produces about 7 Mt of sugar yearly, from a cultivated cane area of about 1 Mha. There are 47 sugar mills with daily processing capacities ranging from 5000 to 40 000 t/d. One of the largest groups is Mitr Phol, which has five modern factories with crushing capacities of 14 000–31 000 t/d in Thailand and five factories in China ranging from 5000 to 15 000 t/d. Through close supervision, Mitr Phol accepts only properly cleaned and loaded green-cut cane. Cane is mostly hand-cut and trash is left on the fields as a protective blanket.

Mitr Phol has invested heavily in byproduct utilisation in recent years. At the Phu Khieo site (‘Mitr Phol Park’), for example, it operates a biomass boiler utilising 85% bagasse and 15% rice husks and corn cobs as fuel and selling 65 MW to the grid. At the Dan Chang site 53 MW are sold.

At Phu Khieo there is also a distillery producing 200 000 L/day and a second distillery at the Kalasin site, both producing fuel-grade ethanol for blending with gasoline. Also at Phu Khieo, there is a particle board plant, already established in 1990 with a capacity of 90 000 m³ per year. It uses more than 200 000 t of bagasse per year.

Finally, through adequate waste-water treatment and usage of excess condensate from the sugar production process, irrigation schemes have been implemented to irrigate cane fields during the dry months. Agricultural extension services and its own sugarcane research station round off a highly successful enterprise.
RAPPORT: ATELIER DE TRAVAIL DE L’ISSCT SUR LES CO-PRODUITS 2009

Par

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MOTS-CLÉS: Cogénération, Chaudières, Manutention de la Bagasse et de la Paille, Éthanol Cellulosique, Vinasse, Biofermentation, Mélasse.

Résumé

L’ATELIER de travail de l’ISSCT sur les Co-Produits s'est tenu à Coimbatore, Inde du 15 au 19 mars 2009 et a attiré 41 participants de huit pays. Il y avait deux thèmes principaux : le lundi fut appelé le ‘Jour de l'énergie’ et les communications traitaient de la production d'énergie sous forme liquide et solide émanant des coproduits, ainsi que de la cogénération d'énergie électrique de la bagasse et de la paille. La participation de l’audience fut très active et les discussions animées. Le mardi des visites furent effectuées à deux usines sucrières notamment Sakhti Sugars et Bannari Aman qui sont équipées de chaudières à haute pression. Sakhti Sugars dispose également d'équipements pour concentrer et incinérer la vinasse alors que Bannari Aman a une unité de biofermentation à partir de la vinasse et des égouts des moulins. Le mercredi a été consacré au ‘Produits dérivés’ et les questions telles que la production des produits chimiques à forte valeur ajoutée par biofermentation de sucre, la production de la pulpe et du papier à partir de la bagasse et l’incorporation de la mélasse pour l'alimentation animale, ont été débattues dans un cercle restreint. Le jeudi, une visite a été effectuée à un complexe industriel impressionnant (SPB – Seshasyee Paper and Boards Ltd. Erode) dédié à la production de papier d’impression et industriel en association avec une usine de sucre (Ponni Sugars) qui fournit de la bagasse à l'usine de papier. Une unité de traitement des eaux usées est commune aux deux activités. L'atelier était organisé et gracieusement sponsorisé par Ponni Sugars (Erode) Ltd., ainsi que par SPB. Tous les communications ont été bien présentées et ont généré des vives discussions et une bonne interaction entre les participants. Les principales conclusions de l'atelier étaient : Compte tenu de la nécessité de réduire les émissions de gaz à effet de serre, l'importance de la cogénération à partir de la bagasse et autre biomasse, ainsi que la production de bioéthanol de la mélasse et du jus de canne ne cessera d'augmenter. Des chaudières à haute pression et cycles efficients (110 barres, 540°C) sont bien établies et les coûts d'investissements sont entrain de diminuer. Des solutions pratiques pour gérer de large volume de vinasse émanant de la production de bioéthanol sont disponibles, mais ces technologies ainsi que les investissements requis doivent être optimisées. Pour couvrir adéquatement les sujets prometteurs, la division en deux sections (énergie et dérivés) doit être retenue pour les ateliers futurs. L'emphasis sur l’un ou l'autre de ces thèmes pourrait varier selon le nombre de contributions reçues. Afin d'encourager une meilleure participation des technologistes avec des emplois de temps chargés, il devrait y avoir deux jours consécutifs de sessions qui seraient suivis de deux jours de visites à des unités industrielles pour le prochain atelier. De nombreuses communications ont été jugées aptes pour être présentées au Congrès de l’ISSCT au Mexique en mars 2010.
INFORME: TALLER DE COPRODUCTOS
DE LA ISSCT, 2009

Por

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PALABRAS CLAVE: Cogeneración, Calderas, Manipulación de
Bagazo y Paja de Caña, Etanol Celulósico,
Vinazas, Biocomposteo, Biofermentación, Mieles.

Resumen

El taller de Coproducios de la ISSCT del 2009 se realizó en Coimbatore, India, del 15-19 de marzo del 2009 y contó con 41 participantes de 8 países. Se identificaron y consideraron dos Temas Principales: El Lunes se denominó ‘Día de la Energía’ y en él se abordó la producción de energía sólida y líquida a partir de los coproducios, así como la cogeneración de energía eléctrica a partir del bagazo y la paja de la caña. Prevalecieron una muy buena participación de la audiencia y vivos debates. El Martes se visitaron dos ingenios azucareros (Sakhti Sugars y Bannan Aman), que tienen calderas de alta presión. Sakhti Sugars posee también equipos para la concentración e incineración de las vinazas, mientras Bannan Aman cuenta con una planta para compostar las vinazas mezcladas con las tortas de los filtros. El miércoles fue el ‘Día de los Derivados’, cuando se debatieron, en grupos más pequeños, aspectos como la biofermentación de azúcar para la obtención de productos químicos de alto valor, la producción de pulpa y papel de bagazo, la adición de mieles finales al alimento animal. El jueves visitamos una impresionante planta productora de papeles de imprenta e industriales (SPB) y un ingenio azucarero adyacente (Ponni Sugars) que provee de bagazo a la planta de papel, así como también un eficiente tratamiento conjunto de aguas residuales. El Taller fue acogido y gratamente patrocinado por Ponni Sugars (Erodes) Ltd., y por SPB-Seshaysee Paper and Board Ltd. Erodes. Todos los trabajos técnicos fueron bien presentados y generaron discusión e interacción entre los participantes. Las principales conclusiones del Taller fueron: En razón de la necesidad de reducir la emisión de gases de efecto invernadero, continuará incrementándose la importancia de la cogeneración con bagazo y otras biomasas, así como la producción de bioetanol a partir de las mieles y jugo de caña; La generación de vapor en calderas de alta presión y ciclos eficientes de generación de potencia (110 bar, 540°C) están bien establecidos y se reducen los costos de inversión; Están disponibles alternativas prácticas para manejar los grandes volúmenes de vinazas residuales de la producción de bioetanol, sin embargo, aún se requiere la optimización de las tecnologías y los volúmenes de las inversiones; Con el fin de cubrir adecuadamente aspectos promisorios, debe mantenerse en futuros Talleres la división en dos (2) Secciones (Energía y Derivados). El énfasis real sobre cualquiera de ellos variará en correspondencia con la cantidad de contribuciones que se reciban; Para promover, en el próximo Taller, una mayor participación de especialistas que disponen de tiempo limitado, deberán realizarse las presentaciones en dos (2) días consecutivos de sesiones, seguidos de dos (2) días de visitas a plantas; Muchos trabajos técnicos discutidos en el Taller se consideran con méritos suficientes para ser presentados en el Congreso de la ISSCT en México en Marzo del 2010.
INTEGRATED PRODUCTION OF ORGANOMINERAL BIOFERTILISER (BIOFOM®) USING BY-PRODUCTS FROM THE SUGAR AND ETHANOL AGRO-INDUSTRY, ASSOCIATED WITH THE COGENERATION OF ENERGY

By

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KEYWORDS: Organomineral Biofertiliser, Vinasse, Ethanol.

Abstract

BRAZILIAN bioethanol and sugar production generates large amounts of vinasse, filter cake and boiler ashes (originated from biomass combustion). On the other hand, the distribution of these by-products in the field is usually inadequate, considering the environmental aspects and the best use of nutrients and organic material present in these by-products. This work presents a study for reprocessing of these by-products into a solid and granular organom ineral biofertiliser developed by Dedini S/A Ind. Base (BIOFOM®), which can be formulated according to the soil and vegetable specific needs. This article shows the process of an integrated BIOFOM, ethanol and electricity from biomass production system for an industrial unit of large capacity. The results of BIOFOM preliminary agronomic greenhouse tests and analysis of process profitability are also shown. These results indicate an excellent internal rate of return (IRR) and attractive payback time as well, resulting from surplus power sales, reduction of chemical fertiliser and fuel consumption, reduction of by-products distribution infrastructure, and decrease (elimination) of the mill’s water withdrawal. Moreover, BIOFOM gave a good agronomic performance in greenhouse use experiments, and it will provide an appropriate reuse of the by-products, in accordance with green technologies. Therefore, the studies show that BIOFOM will lead to the existence of a more profitable and sustainable agro-industry that adopts rational and friendly practices for the environment.

Introduction

According to UNICA (União da Indústria de Cana-de-Açúcar, 2008), 495.7 million tonnes of sugarcane were processed in the Brazilian 2007–2008 milling season, producing 2.5 million m³ of ethanol (anhydrous and hydrated) and 30.9 million tonnes of sugar.

The volume of vinasse generated is about 10 times the volume of ethanol produced, 28 kg to 40 kg/t cane of filter cake, and 6.25 kg/t cane of ash and soot resulting from bagasse burning. These by-products are reused in the cane field, but sometimes the disposal of such materials is not made appropriately, with losses in nutrients, N, P, K and organic matter contained in the by-products.

This paper proposes a profitable production system of a solid and granular organom ineral fertiliser from these by-products for any mill producing ethanol and co-generating electricity. The system permits a significant reduction in the use of chemical fertilisers and diesel oil, thus reducing the greenhouse gas emissions (GGE) and allowing the recovery of water contained in vinasse for reuse in the industry or in the crop (ESALQ, 2007 and 2008; Gurgel, 2009).
Materials and methods

For a technical-economic evaluation of the proposed solution, a case study was carried out for an ethanol producing mill equipped to produce power by cogeneration, with capacity to process 20,000 tonnes of cane per day (Table 1A).

For the purposes of the study, an industrial plant to meet this capacity was dimensioned and price quotations were duly requested. The costs of handling and distribution of the by-products in the cane field (vinasse, filter cake, ash, soot and chemical fertilisers) were calculated, and these costs were compared with those involved in the production and distribution of the organo ineral biofertiliser, called BIOFOM® (Gurgel, 2009; Kiël, 1985; Mantelatto et al., 2007).

To evaluate BIOFOM’s agronomic potential, batches of this fertiliser were produced (see Figure 1) from vinasse, filter cake, ash and soot and complemented with chemical fertilisers, which were granulated and dried (Carmello et al., 2009). The biofertiliser granulation was made in a plate granulator with 35 r/m disc rotation. The experiment (ESALQ, 2009, Carmello et al., 2009) was conducted in the greenhouse of the Department of Soil Sciences of ‘Luís de Queiroz’ College – ESALQ (University of São Paulo, 2009) in Piracicaba, SP.

The experiment was designed for 25 treatments: Control sample, mineral fertiliser 100%, 75% and 50% of 50 kg of N, 100 kg of P₂O₅ and 100 kg of K₂O; BIOFOM from vinasse (resulting from ethanol production), concentrated, 30% and 45% total solids with 100%, 75% and 50% of the N, P and K doses in the treatment with m ineral fertiliser; BIOFOM from vinasse plus sugar, concentrated, 30% and 45% total solids with 100%, 75% and 50% of the N, P and K doses in the treatment with m ineral fertiliser; BIOFOM from vinasse (resulting from sugar production), concentrated, 30% and 45% total solids with 100%, 75% and 50% of the N, P and K doses in the treatment with m ineral fertiliser; concentration of vinasse (30% total solids) from ethanol production with m ineral com plmentation for 100% of 50 kg of N, 100 kg of P₂O₅ and 100 kg of K₂O; concentrated vinasse (30% to tal solids) from ethanol and sugar production with m ineral com plmentation for 100% of 50 kg of N, 100 kg of P₂O₅ and 100 kg of K₂O; concentrated vinasse (30% total solids) from sugar production with m ineral com plmentation for 100% of 50 kg of N, 100 kg of P₂O₅ and 100 kg of K₂O, with four replications each, resulting in 100 plots. All treatments received limestone, including the control sample. Each plot was represented by a 2.5 L capacity pot, wherein 2 kg of earth, 0.625 g of CaCO₃ and 0.625 g of MgO were added.

Two corn seeds were planted in each pot, and the seedlings were then thinned out to one plant per pot on the 5th day of the experiment. The results were evaluated with respect to the foliar area, dry matter of the aerial portions and roots, amount of nutrients in the plant’s aerial portions and roots, and remaining BIOFOM after harvest.

Results

Technical-economic evaluation of the BIOFOM producing unit

Figure 1 shows the organo ineral fertiliser made from cake, ash, soot and concentrated vinasse and complemented with chemical fertiliser, called BIOFOM (Gurgel, 2009; Kiël, 1985; Mantelatto et al., 2007).

Figure 2 presents a chart of the unit operations, feedstock and utilities for BIOFOM production for a basic formulation of the end fertiliser. In this process, filter cake, boiler ashes and soot are mixed and dried. The vinasse generated by the distillation of ethanol is concentrated up to 50% dry substance (DS) in multi-effect vacuum evaporators and is further mixed with a mineral source of N, P and K and sent to be mixed with cake, ashes, and soot previously dried. The mixture is granulated and dried, resulting in a solid organo ineral fertiliser (Figure 1) according to the planned formulation. The energy required for the vinasse concentration is obtained from the integration of energy with distillery, and the dried mixtures result from the combustion in the furnace of bagasse and/or trash (‘straw’) and/or optionally concentrated vinasse.
Fig. 1—BIOFOM.

Fig. 2—BIOFOM flow sheet.
Fertiliser savings with the use of BIOFOM

Table 1 (A) is a summary of the case study of a mill producing ethanol, power and BIOFOM. According to the data presented, a unit processing 3 600 000 tonnes of cane/season (20 000 tonnes of cane/day), equipped with a 67 kgf/cm² boiler that consumes some 430 kg of steam/tonne of processed cane, it is possible to process 1 500 000 L of ethanol/day, cogenerate 65 kWh/tonne of cane, and produce 180 955 tonnes of biofertiliser/season with a formulation (3, 3, 4).

<table>
<thead>
<tr>
<th>Integrated production of BIOFOM in sugar milling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milling of cane (742 tc/h) t/season</td>
</tr>
<tr>
<td>Cane area (harvest base: 86 t/ha) ha</td>
</tr>
<tr>
<td>Cogeneration kWh/tc</td>
</tr>
<tr>
<td>Specific steam consumption kg/tc</td>
</tr>
<tr>
<td>Boiler pressure (abs) kgf/cm²</td>
</tr>
</tbody>
</table>

Vinasse

| Mass flow (3% DS) t/season | 2 387 664 |
| Mass flow (60% DS) t/season | 115 350 |
| Recovery water t/season | 2 272 314 |
| Volume reduction # | 20.7 |

Filter cake

| Mass flow (40%DS) t/season | 104 818 |
| Ash from boiler | |
| Ash from boiler/furnace t/season | 40 680 |

Chemical fertiliser complementary

| Urea (45% of N) t/season | 6265 |
| SSP (21% P205) t/season | 1322 |
| Potassium cloride (KCI) t/season | 196 |

Biofertiliser—BIOFOM

| Total production (85% DS) t/season | 180 995 |
| Specific production of BIOFOM kg/tc | 50 |
| Specific rate of application on land t/ha/year | 4.3 |

In this case, the power used to concentrate vinasse comes from the vegetal steam generated by juice evaporation and the alcoholic vapours of the distillery.

Table 1 (B) shows the savings obtained with BIOFOM fertiliser. According to these data, 35% of nitrogen, 62% of phosphorus and 98% of potassium can be recycled, which reduces dramatically the amount of fertiliser to be purchased.

In the overall picture, about 67% of the fertiliser to be used in the milling season can be optimally recycled and distributed in the field.

In addition, 2 272 314 m³ of water via recovered condensates by vinasse concentration can be used in the industry or in the field.
Table 1(B)—Chemical fertiliser saved by use of BIOFOM.

<table>
<thead>
<tr>
<th>Fertiliser saved by BIOFOM use</th>
<th>Consumption of fertiliser</th>
<th>Fertiliser recycled by BIOFOM</th>
<th>Other compounds recycled by BIOFON</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Urea (45% of N) t/season 9648</td>
<td>3383 (35.1%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SSP (21% P2O5) t/season 4179</td>
<td>2848 (68.1%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Potassium chloride (KCl) t/season 10 287</td>
<td>10 091 (98.1%)</td>
</tr>
<tr>
<td></td>
<td>Total t/season 24 115</td>
<td>Total recycled t/season 16 322 (67.6%)</td>
<td>86 882</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Organic material t/season 3665</td>
<td>CaO t/season 3665</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MgO t/season 1108</td>
<td>MgO t/season 1108</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SO4 t/season 4023</td>
<td>SO4 t/season 4023</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cu t/season 21.2</td>
<td>Cu t/season 21.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Zn t/season 9.3</td>
<td>Zn t/season 9.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mn t/season 46.8</td>
<td>Mn t/season 46.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fe t/season 187.0</td>
<td>Fe t/season 187.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bo t/season 2.8</td>
<td>Bo t/season 2.8</td>
</tr>
</tbody>
</table>

Economic evaluation

To evaluate the economic impact of BIOFOM production and use in the ethanol and energy producing complex, a study considering all investments and the fixed and variable costs for the production of this fertiliser in industrial and agricultural operations was carried out.

The study points out that the main advantage of BIOFOM lies in the reduced expenses with acquisition of fertilisers and the reduction in the investment and operational costs regarding agricultural operations. Vinasse distribution is no longer required, eliminating the need for trucks to transport such huge volumes.

In the case studied, it was assumed that vinasse would be concentrated up to 50% DS before mixing with the filter cake and ashes. A BIOFOM plant was designed for such a system, taking into consideration N, P and K complements to meet exactly the total sugarcane plantation needs.

Fertiliser expenses, which in the BIOFOM process refer to the N, P and K complements, reduced 70% when compared to the use of mineral fertilisers. Investments in trucks and distribution systems showed a reduction about 67% for the worst case (ethanol mill very close to the plantation).

Even when taking into account the extra labour required for the BIOFOM plant, the steam, electricity and bagasse consumption by the BIOFOM process, the net result is very positive.

Considering a capital cost of 12% per year and typical equipment costs, it can be shown that the discounted payback time of such a project ranges from 2 to 3.5 years, depending on the distance between the ethanol mill and the sugarcane plantation.
Another study shows that a water-exporting ethanol mill, based only on vinasse concentration but not producing BIOFOM, is not profitable, due to the low incomes and high investment. Since the BIOFOM process is a step further in that process, including the benefit of water exportation (Gurgel, 2009; Mantelatto et al., 2007), and was demonstrated to be profitable, it can be concluded that BIOFOM is a solution that makes water-exporting mills not only environmentally beneficial but also profitable.

Greenhouse results

Table 2 presents a summary of the comparative results (100% of the formula to sugar-cane) of the samples that were treated with BIOFOM (by using vinasse with 45% DS), conventional fertiliser and those that did not receive fertiliser (control sample). Both those pots fertilised with BIOFOM and those fertilised with a formulation prepared with chemical fertiliser only were prepared to meet 45%, 75% and 100% of the amount of N, P and K required for sugarcane culture. The BIOFOM samples were prepared with three different types of vinasse, obtained from fermentation of mixed juice (J), or molasses (M) or mixtures of molasses and mixed juice (MJ).

After harvesting, 50 days after planting, all samples were evaluated with regards to foliar area, dry mass and nutrients present in the aerial portion of the plants and in the root system, residual N, P and K in soil, and the remaining BIOFOM in the granule after harvest.

As the results presented in Table 2 show, all treatments had significantly better performance than the control sample. Also, there were no significant differences between the treatments with BIOFOM using different vinasses (MJ, M and J).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Part analysed</th>
<th>Mineral fertiliser</th>
<th>BIOFOM (complemented of 100% of formula of cane plantation)</th>
<th>Control sample</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>MJ</td>
<td>M</td>
</tr>
<tr>
<td>Leaf area (cm²)</td>
<td>Leaf area</td>
<td>3.771</td>
<td>2.361</td>
<td>2.903</td>
</tr>
<tr>
<td>Dry substance (g)</td>
<td>Aerial part</td>
<td>20.42</td>
<td>9.55</td>
<td>13.26</td>
</tr>
<tr>
<td></td>
<td>Root</td>
<td>9.14</td>
<td>8.5</td>
<td>8.33</td>
</tr>
<tr>
<td>Nitrogen (mg/dm³)</td>
<td>Aerial part</td>
<td>490.73</td>
<td>222.01</td>
<td>231.01</td>
</tr>
<tr>
<td></td>
<td>Root</td>
<td>128.24</td>
<td>107.31</td>
<td>96.83</td>
</tr>
<tr>
<td></td>
<td>Soil</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>Phosphorus (mg/dm³)</td>
<td>Aerial part</td>
<td>71.43</td>
<td>23.37</td>
<td>27.18</td>
</tr>
<tr>
<td></td>
<td>Root</td>
<td>16.68</td>
<td>9.21</td>
<td>8.15</td>
</tr>
<tr>
<td></td>
<td>Soil</td>
<td>166.75</td>
<td>47.5</td>
<td>35.5</td>
</tr>
<tr>
<td>Potassium (mg/dm³)</td>
<td>Aerial part</td>
<td>702.8</td>
<td>362.87</td>
<td>418.67</td>
</tr>
<tr>
<td></td>
<td>Root</td>
<td>125.09</td>
<td>72.45</td>
<td>89.87</td>
</tr>
<tr>
<td></td>
<td>Soil</td>
<td>1.88</td>
<td>7.48</td>
<td>6.05</td>
</tr>
<tr>
<td>Granules remaining (%) after harvest (50 days after plantation)</td>
<td>DS</td>
<td>nd</td>
<td>51.11</td>
<td>53.16</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>nd</td>
<td>49.56</td>
<td>45.37</td>
</tr>
<tr>
<td></td>
<td>P</td>
<td>nd</td>
<td>81.87</td>
<td>100.00</td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>nd</td>
<td>10.74</td>
<td>19.78</td>
</tr>
</tbody>
</table>

Note: MJ : vinasse from molasses and juice, M: vinasse from molasses, J: vinasse from juice, nd: not detected

The mineral fertiliser produced a bigger mass of dry matter in the aerial portion of the plant, which shows that some of the nutrients present in BIOFOM were not available 50 days after application, which is an advantage in an open system environment where leaching of the mobile nutrients in the soil occurs. In fact, it should be noted that more than 50% of the nutrients in
BIOFOM initially applied remained in the soil after 50 days. It should also be taken into account that, in this experiment, being a closed system, no losses occurred, resulting in a slightly higher efficiency in the treatments where chemical fertiliser was applied.

For sugarcane, whose cycle is 12 to 18 months, there is enough time for the remaining BIOFOM nutrients to be available and, therefore, it can be expected that it responds similarly or even better than the treatments with mineral fertilisers (Carmello et al., 2009). Kiel (1985) reported the benefits of the application of organic matter in soil, which promotes the improvement of the soil physical-chemical properties, the CEC – Cation Exchange Capacity, and porosity, which facilitates the absorption of nutrients and reduces the losses caused by leaching. By using BIOFOM in soil, the same benefits reached with organic matter can be expected, given that at BIOFOM is composed of about 40 to 70% of organic matter, depending on the formulation used.

Conclusions

According to the results obtained, we can conclude that:

- It is evident that BIOFOM is a competitive and sustainable organomineral fertiliser;
- BIOFOM permits an optimum and profitable distribution of sugar, ethanol and energy by-products, which enables recycling of more than 50% of the fertiliser required in sugarcane plantation;
- BIOFOM can be formulated according to the specific needs of the soil, permitting optimum use of chemical fertilisers;
- Additional gains with the use of BIOFOM, because of its high content of organic matter, will be obtained with the improvement of the soil physical-chemical properties, the CEC – Cation Exchange Capacity, and porosity, which facilitates the absorption of nutrients and reduces the losses caused by leaching;
- The economic study showed the feasibility of the project implementation for BIOFOM production: excellent internal rate of return (IRR) and payback time of 2 or 3 years;
- The use of BIOFOM in the crop land allows a significant reduction of the infrastructure required to distribute fertiliser, vinasse, filter cake and ashes;
- With implementation of BIOFOM, it is possible to reduce or even eliminate water withdrawal by the mills by using only the water contained in sugarcane: a portion of the recovered water in vinasse concentration can be reused in the industry or in the field.
- Optimisation of power consumption in the mills in connection with the implementation of a BIOFOM plant will certainly increase the profitability of the sugar and ethanol complex, due to the integrated production of biofertiliser, ethanol, sugar, surplus power generation and water recovery.

REFERENCES


PRODUCTION INTÉGRÉE DE BIOENGRAIS ORGANOMINERAL (BIOFOM ®) À L'AIDE DES SOUS-PRODUITS DU SUCRE ET DE L'AGRO-INDUSTRIE D'ÉTHANOL, ASSOCIÉE À LA COGÉNÉRATION D'ÉNERGIE

Par

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MOTS-CLÉS: Bioengrais Organomineral, Vinasse, Éthanol.

Résumé
LA PRODUCTION de bioéthanol et de sucre au Brésil génère de grandes quantités de vinasse, des tourteaux et des cendres des chaudières (provenant de la combustion de la biomasse). D'autre part, la distribution de ces sous-produits dans le champ est généralement pas satisfaisante, quand l’on considère les aspects environnementaux et la possibilité d’un meilleur usage des éléments nutritifs et des matières organiques présents dans ces sous-produits. Cette communication présente une étude de traitement de ces sous-produits afin de produire un bioengrais organom ineral solide et granulaire développé par Dedini S/A Indiana Base (BIOFOM ®), qui peut être formulé conformément aux caractéristiques du sol et aux besoins spécifiques des plantes. Le procédé d’un système de production intégré de BIOFOM, d’éthanol et d’électricité à partir de la biomasse pour une unité industrielle de grande capacité est décrit. Les résultats des tests préliminaires agronomiques effectués en serre avec le BIOFOM et de l’analyse de rentabilité du procédé sont également présentés. Ces résultats indiquent un excellent taux de retour interne sur l’investissement et le temps de recouvrement est aussi attrayant, etant issu de la vente du surplus d’énergie, de la réduction de la consommation de carburant et des engrais chimiques, de la réduction de l'infrastructure de distribution des sous-produits et de la diminution (élimination) du retrait de l’eau de l’usine. En outre, BIOFOM a donné une bonne performance agronomique dans des essais en serre, et il fournira une réutilisation appropriée des sous-produits, en conformité avec les technologies vertes. Par conséquent, les études montrent que BIOFOM conduira à l’existence d’une agro-industrie plus rentable et durable qui adopte des pratiques rationnelles et favorables à l'environnement.
PRODUCCIÓN INTEGRADA DE FERTILIZANTES ORGANOMINERALES (BIOFOM*) EMPLEANDO SUBPRODUCTOS DE LA AGROINDUSTRIA AZUCARERA Y ALCOHOLEREA, ASOCIADA CON LA PRODUCCIÓN DE ENERGÍA.

Por

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PALABRAS CLAVE: Biofertilizantes Organometálicos, Vinazas, Etanol.

Resumen

LA PRODUCCIÓN de bioetanol y azúcar generan grandes cantidades de vinazas, tortas de los filtros y cenizas de las calderas (originadas de la combustión de la biomasa). Por otra parte, la distribución de estos subproductos en el campo es usualmente inadecuada, considerando los aspectos ambientales y los usos más efectivos de los nutrientes y los productos orgánicos en estos subproductos. Este trabajo presenta un estudio para el reprocessamiento de estos en un organobiofertilizante sólido y granular, desarrollado por DEDINI S/A ind. Base (BIOFOM*), el cual puede formarse en correspondencia con las necesidades de los suelos y los vegetales. Este artículo muestra el proceso de un sistema integrado, BIOFOM*, etanol, energía a partir de biomasa, para una unidad de producción industrial de gran capacidad. Se muestran también los resultados preliminares, de las experiencias agronómicas en invernadero, del BIOFOM*, así como un análisis de los beneficios económicos. Los resultados indican excelentes retornos internos de retorno (IRR) y atractivos tiempos de recuperación de la inversión, resultando de las ventas de energía sobrante, reducción de fertilizantes químicos, y consumo de combustible y en la infraestructura de la distribución de subproductos, junto al decrecimiento (eliminación) de la extracción del agua en el Central. Adicionalmente, BIOFOM* ofrece un buen comportamiento agronómico en los experimentos en invernadero y brindará un reuso apropiado de los subproductos en correspondencia con tecnologías verdes. Por tanto, los estudios muestran que BIOFOM* conducirá a la existencia de una agroindustria más rentable y sostenible, que adopta prácticas racionales y amigables con el entorno.
RHODOTORULA SPP. A POTENTIAL CANDIDATE FOR BIODIESEL PRODUCTION

By

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KEYWORDS: Biodiesel, Microbial Oil, Oleaginous Yeast, Feed Protein, β-Carotene.

Abstract
This paper assesses the production of lipids in Rhodotorula spp. yeast biomass under certain propagation conditions. For lipid accumulation, a double-stage culture was arranged with a full balanced medium for cell propagation and afterwards, under nitrogen deficiency, to initiate the conversion of organic matter into triglycerides. This mode was compared with single-stage culture in terms of cell concentration, lipid productivity, protein content in final biomass, and lipid and biomass yields. Significant differences were found in respect to all parameters tested favouring single-stage culture except for cell concentration that was higher in the double-stage mode. Lipid productivity, the most important parameter, was 0.22 and 0.33 kg/m³/h for double and single-stage cultures respectively, whereas lipid content was 28.60% for double stage and 29.84% for single stage. Protein in final biomass was 29.98 and 30.46% for double and single-stage respectively. This latter is important, since the resulting biomass after lipid extraction can be used as animal feed. Taking into account that yeast production is far more intensive than with vegetal crops, oil-yeast production could be an attractive alternative to oil seeds for biodiesel production.

Introduction
One of the major challenges facing mankind at present is diminishing fossil fuel stocks. The burning of these materials is one of the key factors for global warming due to carbon dioxide and other greenhouse gas emissions. In addition, with the rapid rise in the price of crude oil and projected decrease in oil supplies, there has been increasing interest in biofuels in scientific and entrepreneurial communities (Pahl, 2005; Soriano et al., 2006; Kemp, 2006). To deal with these problems, alternative renewable biofuels are receiving considerable attention (Hill et al., 2006). One of the most prominent renewable energy resources is biodiesel, which is produced from renewable biomass by transesterification of triacylglycerols, yielding monoalkyl esters of long-chain fatty acids with short-chain alcohols: for example, fatty acid methyl esters (FAMEs) and fatty acid ethyl esters (FAEEs).

Biodiesel contributes no net carbon dioxide or sulfur to the atmosphere and emits fewer pollutants than normal diesel (Lang et al., 2001; Vicente et al., 2004). In the production of biodiesel, various renewable lipids have been chosen, including vegetable oils, animal fats and wasting oils (Aggelis et al., 1995).

Palm oil, rapeseed oil, and soybeans have been used to produce biodiesel. However, these require energy and land area for sufficient production. In spite of the favourable impacts that its commercialisation could provide, the economic aspect of biodiesel production has been restricted by the cost of oil raw materials (Antolin et al., 2002). If plant oil was used for biodiesel production, the cost of feedstock accounts for 70–85% of the whole production cost. Therefore, reduction of the high cost of biodiesel is of much interest.
Microorganisms have often been considered for the production of oils and fats as an alternative to agricultural and animal sources. However, a substitute for a fossil fuel should have not only superior environmental benefits or be economically competitive but also must provide a net energy gain over the energy sources used to produce it. Biodiesel production using microbial lipids has attracted increasing attention since it is expected to accomplish these requirements.

Yeasts and fungi (especially moulds) have been considered as favourable oleaginous microorganisms since the 1970s (Hall and Ratledge, 1977). Some yeast strains, such as *Rhodosporidium* sp., *Rhodotorula* sp. and *Lipomyces* sp. can accumulate intracellular lipids as high as 70% of their biomass dry weight.

The most efficient oleaginous yeast, *Criptococcus curvatus*, can accumulate storage lipids up to >60% on a dry weight basis, when it grows under N-limiting conditions, with a percentage of saturated fatty acids of about 44% which is similar to many plant seed oils (Ratledge, 1982). Other authors found similar fatty acid concentration in *Rhodotorula glutinis* grown on sugarcane molasses with N-limitation in the oil accumulation step (Almazan et al., 1981; Alvarez et al., 1992; Diaz et al., 1993; Alvarez and Steinbüchel, 2002). These fatty acids can be extracted, saponified and esterified with low molecular weight alcohols to yield biodiesel. The main limitation of yeast lipids as a feedstock is that they show almost 30% saturated fatty acids with scarce on no nutritional properties. On the other hand, some of these fatty acids have odd carbon numbers which is an additional drawback, as they cannot be metabolised by animals or human beings (Almazan et al., 1981; Alvarez et al., 1992).

The first step in such a production is the efficient accumulation of as much lipid as possible in yeast biomass. It is well known that *Rhodotorula* spp. synthesise yeast when nitrogen or any other important nutrient is scarce in growth medium (Enebo and Iwamoto, 1966; Coccuci et al., 1975).

The propagation step can be arranged in many modes, batch or continuous. The comparison between double-stage or simple-stage continuous culture is the subject of the present paper.

**Materials and methods**

**Microorganism**

*Rhodotorula glutinis* from the ICIDCA collection was propagated in all experiments. Inocula were prepared from agar-malt slants, grown overnight in a medium containing sugarcane molasses at 20 mg/mL of total reducing sugars concentration and nutrient salts (diammonium phosphate and sulfate) to cover cell nutritional requirements in a rotary shaker at 32ºC. A 2.5 L Marubishi MD5 fermentor was used to start batch propagation with the same culture medium at $\mu(=D) = 0.20h^{-1}$.

The exhausted medium with yeast cells was discharged in equal volumes to commence the second stage and was fed with fresh medium without nitrogen containing the same concentration of sugars as the first stage.

For single-stage experiments, the growth medium was the same except that nitrogen was fixed at 70% of nutritional requirements.

Dilution rate ($=\mu$) was set at $0.1h^{-1}$. Other fermentation parameters were temperature 32ºC, pH 4.0 and aeration one volume of air for volume of medium per minute (vvm). All experiments were run for 96 hours.

**Chemical analysis**

Nitrogen was determined according to Kjeldahl (Anon., 1983) in a 1030 Kjeltec Auto System (Tecator AB, Hoganas, Sweden). Reducing sugars were estimated by copper reduction (Greenfield and Geronimus, 1985).

Dry matter was desiccated at 105ºC overnight and lipids by extraction with ethyl ether and desiccation until constant weight in a vacuum oven at 60ºC.
Results

Batch culture

The basic physiology of lipid accumulation in microorganisms has been understood for many years (Enebo and Iwamoto 1966; Hall and Ratledge 1977).

Normally, the organism is cultivated in a medium consisting of an excess of the carbon source and a limited quantity of an inorganic nutrient, usually nitrogen. Other limiting components of the growth medium can also be used to promote lipid accumulation such as P, Mg, etc., but they lead to lower biomass production and hence lower productivity.

When one of the nutrients is depleted, the organism can no longer grow and divide and it starts to synthesise lipids as nutritional stock. Figure 1 shows the behaviour of biomass and lipid concentration under nitrogen limitation.

Continuous culture

Continuous culture has several advantages when compared with batch mode. Productivity increases several times and the whole process is more homogeneous once steady state is achieved.

Lipid accumulation is a typical double-stage process in which cells are propagated under full-requirement conditions and, in a second stage, cells are left to accumulate lipids through nitrogen limitation (Almazan et al., 1981).

A typical fermentation arrangement for double-stage culture can be seen in Figure 2.
Figure 3 shows the pattern of the second stage for lipid accumulation in terms of cell biomass and lipid production. As lower D values favour lipid accumulation, this parameter has to be set up like a batch system to get as much lipid in the final biomass as possible. Under such conditions, lipid productivity ranged from 0.28 to 0.34 mg/mL/h.

The kinetic behaviour of lipid accumulation seems to be as if it were growth associated. This is a consequence of steady state propagation under continuous culture, even at a low dilution rate.

This pattern suggests that it is possible to achieve such a steady state in a unique stage provided that two premises were accomplished: a) nitrogen limitation has to be sufficient to sustain growth, so total absence of this nutrient is not possible, and b) dilution rate must be higher than those values corresponding to maintenance, otherwise growth will not occur.
Given these conditions, single-stage culture was set up at the same temperature and pH as above for double-stage. Total reducing substances were fed at 30 mg/mL and nitrogen with 70% of sufficiency. Finally, D was established at constant value of 0.1h⁻¹.

Single-stage culture was set up according to parameters given in Material and Methods section. Figure 4 shows the behaviour of yeast culture under this arrangement.

Nitrogen limitation up to 30% of cell requirements guarantees similar results as in the double-stage culture in a unique reactor. Lipid productivity, the main interest in this technology, ranges from 0.31 to 0.36 mg/L/h, 6% higher than that obtained in a double-stage arrangement.

![Graph showing cell and lipid concentration in single-stage culture of Rhodotorula glutinis](image)

**Fig. 4—Pattern of cell and lipid concentration in the lipid-accumulation step in continuous single-stage culture of Rhodotorula glutinis.**

**Discussion**

Biodiesel production from microalgae has been suggested by different research groups. These microalgae have the advantage that they are sunlight-driven cell factories that convert carbon dioxide to potential biofuels (Metting and Pyne, 1996; Spolaore et al., 2006) and can provide several different types of renewable biofuels, including methane produced by anaerobic digestion of the algal biomass (Banerjee et al., 2002; Gavrilescu and Chisti, 2005), and they are high lipid microbes. On the other hand, they need larger acreages for culture and a longer fermentation period than bacteria or yeasts.

Bacteria such as *Arthrobacter* sp. and *Acinetobacter calcoaceticus* can accumulate about 20–40% of lipids per dry biomass but propagate at pH values close to neutrality; thus, the probability of foreign contaminants to compete for nutrients is a real drawback.

Yeasts are able to propagate in an ample range of pH, are significantly larger than bacteria, which means lower g values in industrial separators, and yeast culture is widely known everywhere. In addition, in an area slightly larger than two hectares, a 30 t/day factory can be implemented with an output of about 15 t/ha, a yield not achieved by any known oleaginous seed. Therefore, yeast seems to be the most promising candidate for microbial biodiesel production.

Single-stage culture has several advantages over the double-stage arrangement. In addition to a slight increase in lipids and biomass productivity, we have to take into account the capital
investment savings incurred in connection with the number of reactors needed in both arrangements which make single-stage culture less expensive than double-stage.

Some liquid wastes such as distillery vinasse or black liquors from paper industry could be tested to assess its utilisation in this process, which would add another environmental advantage.

In the course of fatty acid production, there are usually some other by-products useable by industry. In addition to oils, oleaginous microorganisms contain significant quantities of proteins, carbohydrates and other nutrient contents (Sanchez et al. 2003); therefore, how to make use of these by-products and improve their industrial value is another way to reduce the production cost of biodiesel.

For example, the residual biomass from biodiesel production can be used potentially as animal feed (Chisti, 2007), and also to produce methane by anaerobic digestion. The waste glycerol from the biodiesel industry could, therefore, be easily transformed into highly valuable chemicals (Hirschmann et al., 2005). *Rhodotorula* spp. produces ß-carotenes (provitamin A) and important proteins useful for animal feeding.

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RHODOTORULA SPP. UN CANDIDAT POTENTIEL POUR LA PRODUCTION DE BIODIESEL

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MOTS-CLÉS: Biodiesel, Huile Microbienne, Levure Oléagineuse, Protéine, d’Alimentation, ß-Carotène.

Résumé
Ce document évalue la production de lipides dans la levure Rhodotorula spp. sous certaines conditions de propagation. Pour l’accumulation des lipides, une culture en deux étapes a été réalisée avec un support équilibré pour la propagation de la cellule et par la suite sous carence azotée pour initier la conversion de la matière organique en triglycérides. Ce mode a été comparé avec une culture en une étape en termes de concentration cellulaire, de productivité des lipides, de teneur en protéines dans la biomasse finale, de rendement en biomasse ainsi qu’en lipides. Des différences significatives ont été trouvées en fonction des paramètres évalués favorisant la culture en une seule étape à l’exception de la concentration de cellule qui a été plus élevée en deux étapes. La productivité en lipides, le paramètre le plus important, était 0.22 et 0.33 kg/m^3/h pour les cultures en
deux étapes et une étape respectivement, considérant que la teneur en lipides était 28.60 % pour la phase double et 29.84% pour la seule étape. Les protéines dans la biomasse finale étaient de 29.98 et 30.46% pour les doubles et simple étape respectivement. Ce dernier point est important, car la biomasse obtenue après l'extraction de lipides peut être utilisée comme aliments pour bétail. Étant donné que la production de levure est beaucoup plus intensive que les cultures végétales, la production de biodiesel à base de levure pourrait être une alternative intéressante aux espèces d’oléagineuses.

**RHODOTORULA SSP. UN CANDIDATO POTENCIAL PARA LA PRODUCCIÓN DE BIODIESEL**

Por

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**PALABRAS CLAVE:** Biodiesel, Aceite Microbial, Leuduras Oleaginosas, Proteínas Comestibles, β-Caroteno.

**Resumen**

Este artículo describe la producción de lípidos en la biomasa de la levadura *Rhodotorula ssp.* Bajo ciertas condiciones de propagación. Para la acumulación de lípidos se estableció un cultivo en doble etapa, con una primera etapa de propagación celular a partir de medio de cultivo totalmente balanceado, seguido de la segunda etapa bajo condiciones de deficiencia de nitrógeno para inducir la conversión de la materia orgánica en triglicéridos. Este esquema se comparó con el cultivo en simple etapa en términos de concentración celular, productividad de lípidos, contenido de proteína en la biomasa final, así como rendimiento de lípidos y biomasa. Se encontraron diferencias significativas con respecto a todos los parámetros estudiados, favoreciendo el cultivo en simple etapa, excepto en lo referido a concentración de biomasa que fue mayor en el esquema de doble etapa. La productividad de lípidos, el parámetro más importante, resultó de 0.22 y 0.33 kg/m³/hr para doble y simple etapa respectivamente, mientras que el contenido de lípidos fue de 28.60% para la doble etapa y 29.84% para simple etapa. Los contenidos de proteína en la biomasa final fueron de 29.98% y 30.46% para simple y doble etapa respectivamente. Esto último es importante, en cuanto la biomasa resultante después de la extracción de los lípidos puede ser empleada como alimento animal. Tomando en consideración que la producción de levadura es mucho más intensa que los cultivos vegetales, la producción de levaduras ricas en grasas resultaría una alternativa atractiva en comparación con el cultivo de semillas de oleaginosas para la producción de biodiesel.
PRODUCTION DIVERSIFICATION FROM SUGARCANE LIGNOCELLULOSIC BYPRODUCTS

By

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KEYWORDS: Sugarcane Biomass, Diversification, Mushroom, Pulp And Paper, Fermentable Sugar.

Abstract

The actual process of sugar and ethanol production in Mexico only uses the carbohydrates in the sugarcane juice and molasses. The remaining material, trash, bagasse and pith, constitutes the lignocellulosic byproducts (biomass) of this industry. In this work, three production alternatives were investigated: edible mushroom Pleurotus ostreatus, pulp and paper and fermentable sugar productions from sugarcane biomass. The characterisation of byproducts was carried out according to AOAC test. For the case of mushroom production, sugarcane trash and a 50:50 mixture of trash and bagasse showed the highest yields (biological efficiencies) of 106% and 103% respectively. For acid hydrolysis, trash samples generated in the local industry were used. Several tests were performed to obtain the maximum production of fermentable sugars using diluted H₂SO₄ at concentration level of 1.0%, temperatures (80–160°C) and hydrolysis times (0 to 330 minutes). A pseudo first-order kinetic model was developed to explain the hydrolysis from sugarcane trash using sulfuric acid. In the last alternative, bagasse pulping and ECF Bleaching (elementary chlorine free) were analysed in detail using TAPPI standards to establish the optimum pulping conditions for this lignocellulosic material.

Introduction

Sugarcane (Saccharum officinarum) is a grass that is harvested for its sucrose content. Sugarcane residue is composed of green cane leaves, tops and what is known as cane residue or trash. After the extraction of sugar from the sugarcane in the mill, the plant material that remains is termed bagasse (Castellan, 1999).

Composition of sugarcane biomass

The chemical characterisation was done according to the TAPPI (2000) and AOAC (1995) methods (Tables 1 and 2).

Table 1—Chemical composition (dry weight) of sugarcane biomass.

<table>
<thead>
<tr>
<th>Components (%)</th>
<th>Trash</th>
<th>Depithed bagasse</th>
<th>Whole bagasse (fibre and pith)</th>
<th>TAPPI test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extractives ETOH-Toluene</td>
<td>3.4</td>
<td>3.8</td>
<td>4.6</td>
<td>T222 om-93</td>
</tr>
<tr>
<td>Extractives H₂O</td>
<td>3.7</td>
<td>4.2</td>
<td>1.3</td>
<td>T207 om-71</td>
</tr>
<tr>
<td>Lignin</td>
<td>24.5</td>
<td>20.7</td>
<td>20.3</td>
<td>T222 om-88</td>
</tr>
<tr>
<td>Holocellulose</td>
<td>78.7</td>
<td>76</td>
<td>74.7</td>
<td>T203 om-93</td>
</tr>
<tr>
<td>α cellulose</td>
<td>47</td>
<td>46.5</td>
<td>45.7</td>
<td>T203 om-93</td>
</tr>
<tr>
<td>Pentoses</td>
<td>25.6</td>
<td>25.2</td>
<td>22.4</td>
<td>T223 om-84</td>
</tr>
</tbody>
</table>
Table 2—Chemical analysis of sugarcane biomass.

<table>
<thead>
<tr>
<th>Components (%)</th>
<th>Ash</th>
<th>Lipids and fat</th>
<th>Crude fibre</th>
<th>Protein</th>
<th>Carbohydrates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depithed bagasse</td>
<td>13.33</td>
<td>0.98</td>
<td>34.11</td>
<td>6.69</td>
<td>33.40</td>
</tr>
<tr>
<td>Sugarcane trash</td>
<td>2.40</td>
<td>0.28</td>
<td>45.00</td>
<td>2.69</td>
<td>38.05</td>
</tr>
<tr>
<td>Whole bagasse (fibre and pith)</td>
<td>7.58</td>
<td>1.24</td>
<td>38.51</td>
<td>1.75</td>
<td>25.82</td>
</tr>
</tbody>
</table>

Production of bagasse pulp

Soda Pulping was performed according to a batch cooking (semi-pilot scale) on depithed bagasse samples (87% fibre and 13% pith) from a sugar mill at Cordoba Veracruz. Four liquor compositions were used as a charge in aqueous caustic soda (NaOH) (19, 17, 15 and 13% as Na₂O on weight percent on a dry basis bagasse and liquid/solid relation 1:7) cooking time (165°C) for 30 min to obtain the lowest kappa number (The Kappa number is determination of relative bleachability or degree of delignification of pulp) (Table 3).

Table 3—Cooking parameters.

<table>
<thead>
<tr>
<th>Liquor composition</th>
<th>Kappa number</th>
<th>Residual lignin (%)</th>
<th>Yield (%)</th>
<th>Shives %</th>
</tr>
</thead>
<tbody>
<tr>
<td>19% Na₂O</td>
<td>13</td>
<td>1.95</td>
<td>51.6</td>
<td>1.1</td>
</tr>
<tr>
<td>17% Na₂O</td>
<td>13.5</td>
<td>2.03</td>
<td>51.3</td>
<td>1.8</td>
</tr>
<tr>
<td>15% Na₂O</td>
<td>16.8</td>
<td>2.52</td>
<td>52</td>
<td>2.5</td>
</tr>
<tr>
<td>13% Na₂O</td>
<td>18.1</td>
<td>2.72</td>
<td>54.5</td>
<td>4.2</td>
</tr>
</tbody>
</table>

The bagasse unbleached pulp (kappa number 18) was subjected to ODP Bleaching (Oxygen delignification, chlorine dioxide and hydrogen peroxide bleaching). Bleaching parameters are presented (Table 4) and strength properties of bagasse pulps to brightness of 90% ISO for this sequence and CEH pulp (conventional bleaching) (Table 5).

Table 4—Bleaching parameters.

<table>
<thead>
<tr>
<th>Bleaching parameters</th>
<th>Bleaching stages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>O</td>
</tr>
<tr>
<td>Kappa No.</td>
<td>18.1</td>
</tr>
<tr>
<td>Pulp consistency (%)</td>
<td>10</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>100</td>
</tr>
<tr>
<td>Treatment time (min)</td>
<td>60</td>
</tr>
<tr>
<td>pH</td>
<td>13.2</td>
</tr>
<tr>
<td>O₂ (kg/cm²)</td>
<td>4</td>
</tr>
<tr>
<td>NaOH (%)</td>
<td>2</td>
</tr>
<tr>
<td>Na₂SiO₃ (%)</td>
<td>–</td>
</tr>
<tr>
<td>H₂O₂ (%)</td>
<td>–</td>
</tr>
<tr>
<td>ClO₂ (%)</td>
<td>–</td>
</tr>
<tr>
<td>MgSO₄ (%)</td>
<td>0.05</td>
</tr>
<tr>
<td>Degree of delignification (%)</td>
<td>70</td>
</tr>
<tr>
<td>Stage yield (%)</td>
<td>90.9</td>
</tr>
<tr>
<td>Overall bleach yield (%)</td>
<td>–</td>
</tr>
</tbody>
</table>

The term used to describe solid content of pulp during pulp processing. For pulp and paper making, this is the most important process parameter. All equipments are designed to handle pulp at and up to certain consistency. Pulp consistency is roughly divided into three ranges: low Consistency: <5%, Medium Consistency: 5 – 15%, High Consistency: >15%.
**Table 5. Strength properties of bagasse pulps (TAPPI, 2000)**

<table>
<thead>
<tr>
<th>Properties / pulp</th>
<th>TAPPI Test</th>
<th>Unbleached pulp</th>
<th>ECF bleached pulp</th>
<th>CEH bleached pulp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shopper Riegler (° S.R.)</td>
<td>T-227</td>
<td>14</td>
<td>20</td>
<td>21</td>
</tr>
<tr>
<td>Freeness (mL C.S.F.)</td>
<td>T-227</td>
<td>653</td>
<td>592</td>
<td>574</td>
</tr>
<tr>
<td>Drainage Time, (Sec)</td>
<td>T-205-sp-95</td>
<td>4.55</td>
<td>5.18</td>
<td>5.09</td>
</tr>
<tr>
<td>Breaking Length, (Metres)</td>
<td>T 404-om-87</td>
<td>5617</td>
<td>5070</td>
<td>4030</td>
</tr>
<tr>
<td>Burst Index, (kPa.m² / g)</td>
<td>T-403 om - 91</td>
<td>3.59</td>
<td>4.17</td>
<td>2.75</td>
</tr>
<tr>
<td>Tear Index (mN.m² / g)</td>
<td>T-414 om - 88</td>
<td>7.85</td>
<td>8.50</td>
<td>7.52</td>
</tr>
<tr>
<td>Folding endurance (#)</td>
<td>T - 423</td>
<td>213</td>
<td>127</td>
<td>34</td>
</tr>
<tr>
<td>Air resistance (Seg. / mL)</td>
<td>T 460 om-02</td>
<td>6.0</td>
<td>11.3</td>
<td>11.07</td>
</tr>
<tr>
<td>Viscosity (Pa.s)</td>
<td>T-230-om-94</td>
<td>0.0365</td>
<td>0.01112</td>
<td>0.017</td>
</tr>
<tr>
<td>Brightness (% ISO)</td>
<td>T-218 om - 91</td>
<td>48.2</td>
<td>89.9</td>
<td>81.2</td>
</tr>
</tbody>
</table>

**Pleurotus ostreatus cultivation in sugarcane biomass**

*Pleurotus ostreatus* has been cultivated on different substrates: sawdust, corncobs, waste paper, straw, bagasse and others byproducts (Mandeel *et al.*, 2005; Contreras *et al.*, 2004).

The substrates, waste wheat straw (control treatment) (*T*₁), sugarcane trash (RAC) (*T*₂), depithed bagasse (BD) (*T*₃), sugar mill bagasse (BI) (*T*₄) and a 50:50 RAC and sugar mill bagasse (*T*₅) were evaluated using a randomised experimental design with five different treatments.

Each substrate was ground, soaked and pasteurised at 85°C by hot water, cooled and packaged in 40 x 60 cm polyethylene bags and inoculated by hand with the spawn (*Pleurotus ostreatus*) in a 5% w/w proportion of fresh substrate weight per test.

The average temperature was 25°C and relative humidity was > 60%. The production was determined according to the biological efficiency (BE). (BE is defined as the weight of fresh mushrooms harvested divided by dry weight substrate at spawning expressed as a percent for each experiment).

**Yield of edible mushroom.**

The highest biological efficiencies were attained by the RAC (*T*₃) substrate and the trash/bagasse mixture (*T*₅). The lowest BE was for sugar mill bagasse (*T*₄). (Table 6).

**Table 6—Biological efficiency (BE).**

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Substrates</th>
<th>Biological efficiency (%) (kg/100 kg substrate)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>T</em>₁</td>
<td>Wheat straw</td>
<td>114.89</td>
</tr>
<tr>
<td><em>T</em>₂</td>
<td>Depithed bagasse</td>
<td>66.64</td>
</tr>
<tr>
<td><em>T</em>₃</td>
<td>Trash</td>
<td>106.64</td>
</tr>
<tr>
<td><em>T</em>₄</td>
<td>Bagasse</td>
<td>70.09</td>
</tr>
<tr>
<td><em>T</em>₅</td>
<td>Trash/bagasse mixture</td>
<td>103.50</td>
</tr>
</tbody>
</table>

The mushrooms from the sugarcane substrates and wheat straw could be dried with direct solar radiation. This processing technology also permits an increase in the value added to mushrooms, to standardise mushroom quality and taste, to highlight properties of mushrooms (Table 7).
Table 7—Chemical analysis of edible mushroom *Pleurotus ostreatus* (% dry weight).

<table>
<thead>
<tr>
<th>Substrates</th>
<th>Components (%)</th>
<th>Ash</th>
<th>Fat</th>
<th>Crude fibre</th>
<th>Protein</th>
<th>Carbohydrates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat straw</td>
<td>8.3</td>
<td>2.2</td>
<td>12.08</td>
<td>20.56</td>
<td>40.96</td>
<td></td>
</tr>
<tr>
<td>Depithed bagasse</td>
<td>6.28</td>
<td>1.48</td>
<td>12.83</td>
<td>17.18</td>
<td>44.78</td>
<td></td>
</tr>
<tr>
<td>Sugarcane trash</td>
<td>7.82</td>
<td>1.79</td>
<td>12.39</td>
<td>19.68</td>
<td>41.2</td>
<td></td>
</tr>
<tr>
<td>Bagasse from mills</td>
<td>5.81</td>
<td>1.94</td>
<td>12.89</td>
<td>15.81</td>
<td>45.14</td>
<td></td>
</tr>
<tr>
<td>Mixture</td>
<td>6.64</td>
<td>1.85</td>
<td>12.65</td>
<td>21.25</td>
<td>40.41</td>
<td></td>
</tr>
</tbody>
</table>

Fermentable sugar from sugarcane trash

Hydrolysis of sugarcane trash was carried out using dilute sulfuric acid solutions (0.5, 1.0 and 1.5%, w/w) in a batch reactor. Operating conditions of the reactor were hydrolysis time (60 to 120 min), temperature (100 to 160°C) and mass ratio of solid to liquid 1:10 on a dry basis.

The determination of the Fermentable Sugars or Recovered acid hydrolysates (%) was evaluated by the Saeman Method (Canizales and Aguilar, 2004) through a 3^3 factorial design with two replications with respect to the interactions of acid concentration (AC), temperature (TEMP) and time (T). Variance analysis was performed with THE SAS SISTEMS® (Table 8).

Table 8—Total sugar yields of glucose and xylose (AFT %) in acid hydrolysis.

<table>
<thead>
<tr>
<th>H2SO4 (%)</th>
<th>Temp. (°C)</th>
<th>Hydrolysis time (min)</th>
<th>Fermentable sugars (%)</th>
<th>H2SO4 (%)</th>
<th>Temp. (°C)</th>
<th>Hydrolysis time (min)</th>
<th>AFT (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>100</td>
<td>60</td>
<td>3.38</td>
<td>1</td>
<td>130</td>
<td>120</td>
<td>13.820</td>
</tr>
<tr>
<td>0.5</td>
<td>100</td>
<td>90</td>
<td>3.5067</td>
<td>1</td>
<td>160</td>
<td>60</td>
<td>16.913</td>
</tr>
<tr>
<td>0.5</td>
<td>100</td>
<td>120</td>
<td>5.4200</td>
<td>1</td>
<td>160</td>
<td>90</td>
<td>15.280</td>
</tr>
<tr>
<td>0.5</td>
<td>130</td>
<td>60</td>
<td>8.8233</td>
<td>1</td>
<td>160</td>
<td>120</td>
<td>14.9467</td>
</tr>
<tr>
<td>0.5</td>
<td>130</td>
<td>90</td>
<td>8.1133</td>
<td>1.5</td>
<td>100</td>
<td>60</td>
<td>16.2500</td>
</tr>
<tr>
<td>0.5</td>
<td>130</td>
<td>120</td>
<td>7.0967</td>
<td>1.5</td>
<td>100</td>
<td>90</td>
<td>15.9967</td>
</tr>
<tr>
<td>0.5</td>
<td>160</td>
<td>60</td>
<td>14.1333</td>
<td>1.5</td>
<td>100</td>
<td>120</td>
<td>16.0433</td>
</tr>
<tr>
<td>0.5</td>
<td>160</td>
<td>90</td>
<td>12.4767</td>
<td>1.5</td>
<td>130</td>
<td>60</td>
<td>14.9433</td>
</tr>
<tr>
<td>0.5</td>
<td>160</td>
<td>120</td>
<td>11.8800</td>
<td>1.5</td>
<td>130</td>
<td>90</td>
<td>16.9600</td>
</tr>
<tr>
<td>1</td>
<td>100</td>
<td>60</td>
<td>11.7300</td>
<td>1.5</td>
<td>130</td>
<td>120</td>
<td>16.2467</td>
</tr>
<tr>
<td>1</td>
<td>100</td>
<td>90</td>
<td>12.3767</td>
<td>1.5</td>
<td>160</td>
<td>60</td>
<td>16.4767</td>
</tr>
<tr>
<td>1</td>
<td>100</td>
<td>120</td>
<td>11.6000</td>
<td>1.5</td>
<td>160</td>
<td>90</td>
<td>18.3467</td>
</tr>
<tr>
<td>1</td>
<td>130</td>
<td>60</td>
<td>16.5033</td>
<td>1.5</td>
<td>160</td>
<td>120</td>
<td>16.3767</td>
</tr>
</tbody>
</table>

The results were statistically significant for interaction AC*TEMP ($R^2 = 0.938491$), and indicated the possibility to obtain a considerable amount of fermentable sugars from sugarcane trash.

Kinetic models

The hydrolysis reactions in dilute-acid medium are very complex (Zheng, 2007, Canizales and Aguilar, 2004; Bustos *et al.*., 2003; Pessoa *et al.*., 1997); based on the Saeman model and the two-fraction model, kinetic parameters for predicting these compounds in the hydrolysates were: $k_1= 0.00702631$ and $k_2=0.0003951$; and the hydrolysis model was $Y = -10.830114 +22.3378444(X_1)+0.07505037(X_2) − 7.1239111 (X_1^2)$ ($Y$: AFT mol/L, $X_1$: sulfuric acid %, $X_2$...
Temperature °C). The optimal conditions selected were 160°C, 1.5% H₂SO₄, and 38.52 min (2311.2 seg) (Table 9).

**Table 9**—Kinetic parameters in the hydrolysis of sugarcane trash with sulfuric acid.

<table>
<thead>
<tr>
<th>Hydrolysis time Sec.</th>
<th>Holocelulose Mol/m³</th>
<th>AFT Mol/m³</th>
<th>Degradation products Mol/m³</th>
<th>raA</th>
<th>raB</th>
<th>raC</th>
</tr>
</thead>
<tbody>
<tr>
<td>2278.8</td>
<td>1.00497127</td>
<td>1.0149045</td>
<td>0.54412423</td>
<td>-0.000412138</td>
<td>5.2514E-06</td>
<td>0.0000406886</td>
</tr>
<tr>
<td>2289.6</td>
<td>1.00052018</td>
<td>1.01496122</td>
<td>0.5485186</td>
<td>-0.000391232</td>
<td>3.3887E-06</td>
<td>0.0000406924</td>
</tr>
<tr>
<td>2300.4</td>
<td>0.9960888</td>
<td>1.01499782</td>
<td>0.55291338</td>
<td>-0.000384955</td>
<td>1.55E-06</td>
<td>0.0000406945</td>
</tr>
<tr>
<td>2311.2</td>
<td>0.99167706</td>
<td>1.01501456</td>
<td>0.55730839</td>
<td>-0.000406686</td>
<td>-2.6481E-07</td>
<td>0.0000406951</td>
</tr>
<tr>
<td>2322</td>
<td>0.98728485</td>
<td>1.0150117</td>
<td>0.56170346</td>
<td>-0.000404885</td>
<td>-2.0559E-06</td>
<td>0.0000406941</td>
</tr>
<tr>
<td>2332.8</td>
<td>0.98291209</td>
<td>1.01498949</td>
<td>0.56609841</td>
<td>-0.000403091</td>
<td>-3.8238E-06</td>
<td>0.0000406915</td>
</tr>
<tr>
<td>2343.6</td>
<td>0.97855871</td>
<td>1.0149482</td>
<td>0.5704931</td>
<td>-0.000401306</td>
<td>-5.5684E-06</td>
<td>0.0000406874</td>
</tr>
</tbody>
</table>

The results emphasize the remarkable potential of sugarcane biomass for applications for the extractive, chemical, food and biochemical industry with sustainable technologies for sugarcane farmers, sugar mills or by products industries. The diversification is a complement to sugar production, improving the exploitation of sugarcane and contributing in this way to the sustainability of the Mexican sugar economy.

**REFERENCES**


DIVERSIFICATION PRODUCTIVE DE SOUS-PRODUITS LIGNOCELLULOSIQUE DE LA CANNE À SUCRE

Par


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MOTS-CLÉS: Biomasse de Canne à Sucre, Diversification, Champignons, Pâtes et Papiers, Sucres Fermentescibles.

Résumé

LE PROCESSUS RÉEL de la production de sucre et d'éthanol au Mexique utilise uniquement les carbohydrates dans le jus de la canne et de la mélasses. Les autres matières, paille, bagasse de canne à sucre de par leur caractère, constituent les sous-produits lignocellulosiques (biomasse) de cette industrie. Trois axes de production ont été étudiées: production du champignon comestible Pleurotus ostreatus, pâtes et papiers et sucres fermentescibles à partir de la biomasse de la canne. La caractérisation des sous-produits a été effectuée conformément au protocol AOAC. Dans le cas de la production de champignons, la paille de canne et un mélange 50/50 de paille et de bagasse ont démontré des rendements plus élevés (efficacité biologique) de 106% et 103% respectivement. Pour l'hydrolyse acide, des échantillons de paille générés dans l'industrie locale ont été utilisés. Plusieurs tests ont été réalisés pour obtenir la production maximale de sucres fermentescibles à l'aide de l'acide sulfurique dilué à une concentration de 1.0%, des températures de 80 à 160°C et la durée de l'hydrolyse (0 à 330 minutes). Un modèle de cinétique de premier ordre a été développé pour expliquer l'hydrolyse de la paille de canne à l'aide d'acide sulfurique. Dans la dernière alternative, la bagasse et l'ECF blanchi (sans chlore) ont été analysés en détail à l'aide des normes TAPPI pour établir le mélange optimal pour produire de la pulpe à partir de ce matériau lignocellulosique.
DIVERSIFICACIÓN PRODUCTIVA A PARTIR DE LOS SUBPRODUCTOS LIGNOCELULÓSICOS DE LA CAÑA DE AZÚCAR.

Por

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PALABRAS CLAVE: Biomasa de la Caña de Azúcar,
Diversificación, Hongos Comestibles, Pulpa y Papel.

Resumen

El proceso de producción de azúcar y alcohol en México actualmente emplea solamente los carbohidratos de los jugos de la caña y las melazas. Los restantes materiales, paja de caña, bagazo y meollo, constituyen los subproductos lignocelulósicos (biomasa) de la industria. En este trabajo se investigaron tres alternativas de producción: hongos comestibles, pulpa y papel y la producción de azúcares fermentables a partir de la biomasa de la caña de azúcar. La caracterización de los subproductos se realizó de acuerdo a las pruebas AOAC. Para el caso de producción de hongos comestibles, la paja de la caña y una mezcla 50:50 de paja y bagazo presentaron los mayores rendimientos (eficiencias biológicas) de 106% a 103% respectivamente. Para la hidrólisis ácida se emplearon muestras de paja de caña generadas en la industria local. Se realizaron varias pruebas para obtener la máxima producción de azúcares fermentables, empleando ácido sulfúrico diluido a una concentración de 1.0%, temperatura de 80-160°C y tiempo de hidrólisis entre 0 y 330 minutos. Se desarrolló un modelo cinético de pseudo-primer orden para explicar la hidrólisis de la paja de caña empleando ácido sulfúrico. En la última opción se desarrollaron en detalles pulpeo de bagazo y blanqueado ECF (elementary chlorine phase) utilizando estándares TAPPI para establecer las condiciones óptimas de pulpeo para este material lignocelulósico.
BIODIESEL STARTING FROM NON EDIBLE OILS AND ETHANOL FOR SELF-CONSUMPTION IN THE AGRO INDUSTRIAL PRODUCTION OF SUGAR AND OTHER FOODS

By

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KEYWORDS: Renewable, Energy, Biodiesel, Ethanol, Biofuels.

Abstract

The decrease of fossil fuels in the near future and climate change constitute the main drivers at the present time for the development of biofuels. They are doubly relevant to the sugar industry because it is a consumer of fuels as well as a potential producer. This paper shows the results of an experimental preliminary study with oleaginous plants, which can be cultivated in soils unsuitable for the production of food, with high yields of around 1 t/ha. Experiences of the synthesis of fuel from such oil and ethanol are reported, which turn out to be somewhat complex but allow the production of biodiesel starting from totally renewable sources with important environmental advantages. An example is shown in which it is possible to achieve biodiesel production to substitute for the consumption of all agricultural diesel by using a small percentage of the land belonging to a farm complex for the production of sugar and other foods. Results for the use in cane transport, at mixtures of 5, 10, 20, 50 and 100% (total substitution) of biodiesel are also presented.

Introduction

According to experts, petroleum prices will tend to increase (US. Department of Energy. September 2008; US Senate, 2005; Benjamin, 2007). It could be strategically important for the agro-industrial production sector (for example, sugar production) to introduce new energy alternatives using renewable sources, as in the case of biodiesel that uses raw materials such as oils of vegetable origin that can be obtained every year and of ethanol that also comes from a renewable source.

We have designed a small plant for biodiesel production using the oil of *Jatropha curca* or *Ricinus communis* as the source of fatty acids. They are oleaginous plants producing non-edible oils and are adapted well to soils which are not fit for food production.

Consequently, there is no competition for the use of soils where foods can be produced.

The biodiesel to be produced would allow the substitution of the diesel fuel that is currently used as the main energy source in the production of foods including sugarcane.

The proposal is to install the biodiesel production plant in a strictly agricultural production farm or in an agro-industrial complex with the purpose of substituting in a partial or total way the consumption of diesel fuel either partially or totally.
The process of biodiesel production is already common in the world, mainly using edible oils whose production in commercial plantations is much more extensive, for example, soy or sunflower oils. In almost all the processes, methanol is used that allows a quicker synthesis process and, in many cases, with slightly higher yields. Methanol has a higher price than ethanol, and the latter allows the production of biodiesel starting from completely renewable sources and it has less effect on the environment and, for these reasons, ethanol was selected for use in the process of this plant.

The complexities for the synthesis from ethanol have already been solved in the ICINAZ up to and including the pilot plant scale. Biodiesel could be employed in mixtures substituting 10, 20, 50% of the diesel fuel, even up to B100 (100% biodiesel) provided that it fulfils the quality specifications of the existing standards.

Results of the simulation of a plant for the production of biodiesel with the software Super Pro Designer version 3.04

With the designed plant, a study was conducted to enlarge the capacity until arriving at one acceptable time of recovery. The results of this study of sensitivity appear in Table 1.

Table 1—Analysis of the plant capacity influence upon the time of investment return.

<table>
<thead>
<tr>
<th>Capacity (t/year)</th>
<th>Time of investment return (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>64</td>
<td>6.54</td>
</tr>
<tr>
<td>160.3</td>
<td>4.43</td>
</tr>
<tr>
<td>320</td>
<td>2.70</td>
</tr>
</tbody>
</table>

Increasing production capacity of one alternative to another, it also increased the capacity of the equipment and the tanks, as well as their costs.

The simulation included a non-complex technology, without glycerine purification nor recovery of the solvent used, and this gave a minimum capacity of 320 t per year of biodiesel for the given costs of the raw materials, selling price of the biodiesel (similar to diesel fuel), cost of labour, cost of equipment, etc. The calculated capacity is similar to the planned diesel fuel expenditures of the ‘Honduras’ agricultural enterprise to which this farm belongs. Any variation in the values of some of these variables has an influence on the time of the return of the investment. This can be shown in the sensitivity analysis carried out in the 160.3 t/y plant when the price of alcohol diminishes (Pérez, 2006) (Table 2).

Table 2—Analysis of the influence of the alcohol price on the time of return of the investment in the plant of 160.3 tonnes/year.

<table>
<thead>
<tr>
<th>Price of the alcohol (cents/L)</th>
<th>Time of return of the investment (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.56</td>
<td>4.43</td>
</tr>
<tr>
<td>0.44</td>
<td>3.76</td>
</tr>
</tbody>
</table>

Study of the behaviour of a Yuchai motor with different biodiesel proportions in the diesel mixture (Alfonso, 2008).

Tests were conducted in the engine testing setup of the CETER, for which standard samples of diesel fuel and mixtures of this with biodiesel in different compositions were used. Measurements were conducted for the following parameters – Effective Power (Ne), Torque (Me), Hourly fuel consumption (Gc) and Specific Consumption (gc) – against frequency of revolution (r/min) when the fuel control valve is completely open, that is, when the maximum dosage of fuel is achieved (Table 3). This parameter gives useful information when giving the maximum parameters
of power and torque with their minimum specific consumption and the revolutions at which these are obtained.

**Table 3**—Technical specifications of the YUCHAI motor (which is used in the trucks hauling sugarcane).

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model.</td>
<td>YC61108Q</td>
</tr>
<tr>
<td>Type.</td>
<td>Vertical, on-line, four cycles, water cooling</td>
</tr>
<tr>
<td>Combustion camera.</td>
<td>Direct injection</td>
</tr>
<tr>
<td>Number of cylinders.</td>
<td>6</td>
</tr>
<tr>
<td>Diameter of the cylinder. (mm)</td>
<td>108</td>
</tr>
<tr>
<td>Piston stroke. (mm)</td>
<td>125</td>
</tr>
<tr>
<td>Compression ratio.</td>
<td>16.5:1</td>
</tr>
<tr>
<td>Nominal power. (KW)</td>
<td>112</td>
</tr>
<tr>
<td>Nominal revolution. (r/min.)</td>
<td>2800</td>
</tr>
<tr>
<td>Torque maximum. (Nm)</td>
<td>428</td>
</tr>
<tr>
<td>Revolutions at maximum torque. (rpm.)</td>
<td>1600–1900</td>
</tr>
<tr>
<td>Minimum fuel consumption at full load (kg/h)</td>
<td>224.4</td>
</tr>
<tr>
<td>Proportion of consumption of fuel and of oil. (%)</td>
<td>0.8</td>
</tr>
<tr>
<td>Temperature of escape gases. (°C)</td>
<td>650</td>
</tr>
<tr>
<td>Number of escape smoke. (Bosch)</td>
<td>4.0</td>
</tr>
<tr>
<td>Mean piston speed. (m/s)</td>
<td>11.7</td>
</tr>
</tbody>
</table>

**Test results**

With the study of the combustion of the biodiesel in a motor and with the parameters of operation of the diesel, it was possible to reach the following conclusions:

- When the biodiesel content increases above 20%, the characteristics of the motor diminish slightly and a slight increase of the specific consumption of fuel was observed.
- The emissions of NOx diminish markedly as the biodiesel content is increased, which could be due to the decrease in the temperature in the combustion chamber as the content of biodiesel increases.
- The appropriate mixture for use in this Motor of Internal Combustion is B20, that is to say 20% biodiesel, because with this you achieve a compromise between the emissions and the benefits of the motor.

It is important to point out that these results were obtained without physical or operational modification to the motor. Even better behaviour for the biodiesel and the mixtures should be expected by correcting the angle of injection of the motor.

**Preliminary results of the agricultural parameters in the ‘Paraguay’ farm**

The study of the behaviour of *Ricinus communis* in the soils of category N of the ‘Paraguay’ farm began in the year 2007 with two species coming from the farm denominated red and green.

Later on, the Imias species labelled white was incorporated in the year 2008. In the year 2008, the study of the *Jatropha curcas*, variety of Cape Verde, coming from the bank of germplasm of CATEDES also began (Center of the CITMA, located in Guantánamo province)(Table 4).
Table 4—Yield behaviour during 2008 and 2009.

<table>
<thead>
<tr>
<th>Oleaginous species</th>
<th>Planting frame</th>
<th>Year of crop</th>
<th>Yield in fruits (kg/ha)</th>
<th>Yield in oil (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Ricinus</em> (green species)</td>
<td>2.4*2.4</td>
<td>2008</td>
<td>881.2</td>
<td>294</td>
</tr>
<tr>
<td><em>Ricinus</em> (red species)</td>
<td>2.4*2.4</td>
<td>2008</td>
<td>1249</td>
<td>416.3</td>
</tr>
<tr>
<td><em>Ricinus</em> (green species)</td>
<td>2.4*2.4</td>
<td>2009</td>
<td>406.2</td>
<td>135.4</td>
</tr>
<tr>
<td><em>Ricinus</em> (red species)</td>
<td>2.4*2.4</td>
<td>2009</td>
<td>1187.5</td>
<td>400</td>
</tr>
<tr>
<td><em>Ricinus</em> (species of Imias)</td>
<td>3*3</td>
<td>2009</td>
<td>780</td>
<td>260</td>
</tr>
<tr>
<td><em>Jatropha curcas</em> (Green End)</td>
<td>4*3</td>
<td>2009</td>
<td>94.3</td>
<td>31</td>
</tr>
</tbody>
</table>

The experimental areas had been subjected to an extreme drought for 6 months. However, a suitable yield was obtained particularly in the case of the *Ricinus* red species coming from the same ‘Paraguay’ farm.

Food security requires two fundamental aspects:
- Availability of fuel sources for the production of foods (quantity and prices).
- No use of foods for energy production

This compromising situation can be avoided if such premises are applied as:
- Using oleaginous plants for biodiesel. These are not used for the production of food or other uses such as microalgae fermentation in residual waters.
- The use of oleaginous plants that can be planted in degraded soils not fit for food production (*Jatropha curcas* and *Ricinus communis*) as the present study shows.
- Stimulate the local production of biodiesel with the purpose of substituting it in agricultural machinery, pumping stations, electrical power-plants, etc.

Conclusions

Positive results were obtained in biodiesel production with ethanol, at the pilot plant level. The use of the produced biodiesel and their mixtures with diesel in motors of trucks hauling sugarcane were good in spite of not making any modifications to the motor. -Preliminary and encouraging results exist in the exploitation of experimental areas of so called N soils with *Jatropha* and *Ricinus*.

Recommendations

- To continue the studies in the ‘Paraguay’ farm and in other edapho-climatic areas of the different species of oleaginous plants of non-edible oils.
- To continue studies in the use of biodiesel in the main types of diesel motors used for agricultural purposes.
- To continue studying the synthesis of ethyl esters using as starting materials the raw oils of *Jatropha* and *Ricinus*.

REFERENCES

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LE BIODIÉSEL À PARTIR D'HUILES NON COMESTIBLES ET D'ÉTHANOL POUR LA CONSOMMATION INTERNE DANS LA PRODUCTION AGRO INDUSTRIELLE DE SUCRE ET D'AUTRES DENRÉES ALIMENTAIRES

Par

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MOTS-CLÉS: Énergies Renouvelables, Énergie, Biodiesel, Éthanol, Biocarburants.

Résumé

LA DIMINUTION de combustibles fossiles dans un avenir proche et les changements climatiques constituent les principales motivations à l'heure actuelle pour le développement des biocarburants. Elles sont doublement pertinentes à l'industrie sucrière car elle est consommatrice d'énergie aussi bien que producteur potentiel. Cette communication présente les résultats d'une étude préliminaire expérimentale avec des plantes oléagineuses produisant des huiles non comestibles telles que le Jatropha curcas et Ricinus communis, qui peuvent être cultivées dans les sols improprens à la production de denrées alimentaires, avec des rendements élevés d'environ 1 t/ha. Des expérimentations de la synthèse de telles huiles et de bioéthanol sont rapportées. Elles se sont avérées quelque peu complexes mais ont permis la production de biodiesel à partir de sources totalement renouvelables avec les avantages environnementaux concrets. A titre d'exemple il est démontré qu'il est possible de produire suffisamment de biodiesel équivalent à la consommation totale de diesel agricole à l'aide d'un faible pourcentage des terres appartenant à une ferme orientée vers la production de sucre et d'autres aliments. Des résultats pour l'utilisation dans le transport de la canne à sucre, à des mélanges de 5, 10, 20, 50 et 100% (substitution totale) de biodiesel sont également présentés.
BIODIESEL A PARTIR DE ACEITES NO COMESTIBLES Y ETANOL PARA EL AUTOCONSUMO EN LA PRODUCCIÓN AGROINDUSTRIAL DE AZÚCAR Y OTROS ALIMENTOS

Por

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PALABRAS CLAVE: Renovable, Energía, Biodiesel, Etanol, Biocombutibles.

Resumen

El decrecimiento de los combustibles fósiles en el futuro cercano y el cambio climático constituyen los principales impulsores actuales para el desarrollo de biocombustibles. Éstos son doblemente relevantes a la industria azucarera porque es una consumidora de combustibles, así como una potencial productora. El artículo presenta los resultados de un estudio experimental preliminar con plantas oleaginosas productoras de aceites no comestibles como la Jatropha curca y Ricinos communis, que pueden ser cultivadas, con altos rendimientos de cerca de 1 t/ha, en suelos no aptos para la producción de alimentos. Se reportan experiencias de la síntesis del combustible a partir de estos aceites y etanol, que resultan ser algo complejas, pero permiten la producción de biodiesel a partir de recursos totalmente renovables con importantes ventajas ambientales. Se muestra un ejemplo en el que es posible alcanzar una producción de biodiesel para sustituir la totalidad del consumo agrícola de diesel, con el uso de un pequeño 5 de tierras que pertenecen a un complejo agrícola dedicado a la producción de azúcar y otros alimentos. Se presentan también resultados de su uso en el transporte de caña, en mezclas de 5, 10, 20, 50, y 100% (sustitución total) de biodiesel.
THE BIOFUELS: A CLEAN AND RENEWABLE ENERGY OPTION FROM SUGARCANE JUICES?

By

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KEYWORDS: Biofuels, Biodiesel, MTBE, Ethanol, Gasohol.

Abstract

PRESENT day gasohol and biodiesel from a mixture with ethanol emerge not only as renewable fuels but also as a support to the sugarcane agro-industrial sector. To synthesise a cubic metre of ethanol, about 12 to 13.5 t of sugarcane are needed. The increasing interest in ethanol production is due to the unavoidable need for energy diversification and the wish of many countries to reduce the emission of greenhouse gases according to the Kyoto protocol. In 2007, 5.57 million cubic metres of ethanol were produced worldwide, 2.0 million m³ in Brazil from sugarcane. In addition, biodiesel production is estimated to increase 10–12% annually from current levels of 985 000 m³. Pure biodiesel is biodegradable and non toxic, and eliminates contamination and toxic emissions as well as aromatic components present in fossil fuels. Brazil is the Latin American leader in R&D and promotion of ethanol use, while Mexico has been far behind in that subject. The mixtures of gasohol E10 and E85 are used in all vehicle types improving their performance. In addition, by MTBE substitution, contamination is reduced. At the beginning, MTBE appeared to be the best additive, but later it was proven to have a carcinogenic effect that could provoke genetic modifications and contribute to formation of ‘photochemical smog’. MTBE is still used in many countries through the import of large amounts of this additive. The promotion of biofuels must be based on the edification of a solid culture about their benefits to human health and the environment. The substitution of MTBE by ethanol and the subsequent addition of ethanol with vegetable oils to obtain biodiesel could increase dramatically the ethanol demand in the market. This paper deals with the actual possibilities and limitations of biofuels production in sugar-producing countries from technological and socio-economical points of view.

Introduction

Much has been discussed in several cane sugar producing countries about the possibilities of developing an ethanol fuel program. However, most of these initiatives have been frustrated due to apparently economical reasons, although today the concept is being re-examined.

Gasohol and biodiesel, blended with ethanol, are emerging as the renewable fuels of the future. This comes from the health point of view and to support the sugarcane agricultural and industrial sectors which have been affected by several well known causes (Lois, 2003).
Today, the importance of the energetic matters all over the world causes us to be in permanent search for those alternatives which can be economical options regarding the availability of oil fuels. World trade in ethanol is shown graphically in Figure 1, and the main uses of ethanol are shown in Figure 2.

The main producers of ethanol are shown in Table 1. A comparison of ethanol production in Brazil, the USA and Europe is presented in Figure 3.

![World ethanol trade graph](image1)

*Fig. 1—World ethanol trade.*

![Main world uses of ethanol](image2)

*Fig. 2—Main world uses of ethanol (Albanesse, 2006).*

<table>
<thead>
<tr>
<th>Country</th>
<th>Production (million litres, 2005)</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>16 214</td>
</tr>
<tr>
<td>Brazil</td>
<td>16 067</td>
</tr>
<tr>
<td>China</td>
<td>3800</td>
</tr>
<tr>
<td>India</td>
<td>1700</td>
</tr>
<tr>
<td>France</td>
<td>910</td>
</tr>
<tr>
<td>Total</td>
<td>44 875</td>
</tr>
</tbody>
</table>

*Table 1—Ethanol production by countries.*
The importance of the gasohol production

Ethanol (C₂H₅OH) mixed with gasoline forms biogasoline or *gasohol* E10 (10% of ethanol in the mix and 90% of gasoline), but the ethanol could be used in higher amounts like *E85* (85% of ethanol). The gasohol improves the octane number of the fuel mix and also of the emissions of the motors.

**What is biodiesel?**

Biodiesel is a cleaner and safer liquid fuel of vegetable origin obtained from renewable sources, such as vegetable oils and animal fats, by means of a process known as transterification; today the EU supplies around 66% of the world biodiesel production with 6500 million litres per year. Brazil has decided to mix 3.0% biodiesel with all the diesel commercialised in the country. The pure biodiesel is biodegradable, non toxic, and mainly free of sulfur and aromatic substances. A mix of 20% biodiesel with petroleum diesel or 25% with ethanol and conversion catalyst totally eliminates air pollution.

**What is methyl-tertiary-butyl ether (MTBE)?**

It’s an oxygenating agent obtained by the reaction of isobutylene and methanol, widely used as an additive in gasoline and a substitute for lead tetraethyl (CH₂CH₃)₄. Initially, it appeared to have good performance, but lately it has been proved to be highly toxic. In México it’s still widely used.

**Steps and challenges for the development of a strategic program of biofuels from sugarcane juices**

i) Public acceptance and support for ethanol as fuel or as *gasohol* and *biodiesel*.

ii) Economic viability in the use of local production facilities for the manufacture of ethanol from locally produced cane juice.

iii) To learn more about the ecological and health benefits from the removal of MTBE and its substitution by ethanol obtained from sugarcane.
iv) Diversification of sugarcane production by the manufacture of higher value-added co-products.

Conclusions

- The removal of MTBE by ethanol for the production of biofuels could dramatically increase ethanol demand.

  In this way, the sugar industry would be able to double its production capacity in a short time and satisfy the demand originated by the replacement of MTBE.

- The net increase in the ethanol production capacity must be as a result of an improvement in agricultural yields in the cane fields, as well as a diversified use of the existing sugar mills. All this will have a solid positive impact over net production and income, and will increase employment possibilities in the country.

REFERENCES


LES BIOCARBURANTS: UNE OPTION D'ÉNERGIE PROPRE ET RENOUVELABLE A PARTIR DU JUS DE CANNE À SUCRE

Par

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MOTS-CLÉS: Biocarburants, Biodiesel, MTBE, Éthanol, Gasohol.

Résumé

DE NOS JOURS, l’essence et le biodiesel en mélange avec l’éthanol émergent non seulement comme combustibles renouvelables, mais aussi comme un soutien au secteur agro-industriel de la canne. Pour synthétiser, un mètre cube d’éthanol, il faut environ 12 à 13.5 tonnes de canne. L’intérêt croissant pour la production d’éthanol est dû à la nécessité incontournable de diversification de l’énergie et le souhait de nombreux pays de réduire les émissions de gaz à effet de serre dans le protocole de Kyoto. En 2007, 5.57 millions de mètres cubes d’éthanol ont été produits dans le monde entier comprenant 2.0 millions de m³ au Brésil a partir de la canne. En outre, la production de biodiesel est voulue à augmenter de 10–12% par an part rapport au niveau actuel de 985 000 m³. Le biodiesel pur est biodégradable et non toxique et élimine la pollution et les émissions toxiques, ainsi que des composants aromatiques présents dans les combustibles fossiles. Le Brésil est le leader latino-américain dans la recherche, le développement et la promotion de l'utilisation de l'éthanol, tandis que le Mexique a été loin derrière dans ce domaine. Les mélanges d’essence E10 et E85 sont utilisés dans tous les types de véhicules pour améliorer leurs performances. En outre, par substitution au MTBE, la pollution est réduite. Au début, le MTBE semblait être le meilleur additif,
mais il a été prouvé éventuellement qu’il avait un effet cancérigène susceptible de provoquer des modifications génétiques et de contribuer à la formation de brouillard photochimique. Le MTBE est toujours utilisé dans de nombreux pays comme le prouve par le biais de l’importation de grandes quantités de cet additif. La promotion des biocarburants doit être basée sur l’élaboration d’une campagne intense sur leurs avantages pour la santé humaine et l’environnement. La substitution du MTBE par l’éthanol et le mélange ultérieur de l’éthanol aux huiles végétales pour obtenir le biodiésel pourraient faire augmenter considérablement la demande d’éthanol sur le marché. Cette communication traite des possibilités réelles et les limites de la production de biocarburants dans des pays producteurs de sucre du point de vue technologique et socio-économique.

LOS BIOCOMBUSTIBLES: UNA OPCIÓN LIMPIA Y RENOVABLE A PARTIR DE LA CAÑA DE AZÚCAR

Por

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PALABRAS CLAVE: Étanol, Biodiesel, No-Contaminación, Efecto Invernadero, Biocombustibles.

Resumen

En la actualidad el gasohol y el biodiesel con una mezcla con etanol emergen no solo como combustibles renovables, sino también como un soporte para el sector agro-industrial azucarero. Para sintetizar un metro cúbico de etanol se requieren entre 12 y 13.5 t de caña de azúcar. El creciente interés en la producción de etanol se debe a la inevitable necesidad de diversificar las fuentes energéticas y el deseo de muchos países de reducir la emisión de gases de efecto invernadero de acuerdo con el Protocolo de Kyoto. En el 2007 se produjeron en el mundo 5.57 millones de m³ de etanol, 2.0 millones en Brasil, a partir de la caña de azúcar. Por otra parte, la producción de biodiesel se estima crece entre 10 y 12% anualmente a partir del actual nivel de 985 000 m³. El biodiesel puro es biodegradable y no-tóxico, elimina la contaminación y las emisiones toxicas, así como los compuestos aromáticos presentes en los combustibles fósiles. Brasil es el líder latinoamericano en la I&D y la promoción del uso del etanol, México, sin embargo, está muy detrás en este aspecto. Las mezclas de gasohol E10 y E85 se utilizan en todo tipo de vehículos, mejorando su desempeño. Adicionalmente, al sustituir el MTBE se reduce la contaminación. En un inicio el MTBE pareció ser el mejor aditivo, pero posteriormente se comprobó que tenía efectos cancerígenos, que podía provocar modificaciones genéticas y contribuir a la formación de ‘nieblas fotoquímicas’. El MTBE se emplea aún en muchos países, importándose grandes cantidades de este aditivo. La promoción de los biocombustibles debe basarse en la edificación de una sólida cultura de sus beneficios a la salud humana y el entorno. La sustitución del MTBE por etanol y la combinación del etanol con aceites vegetales para obtener biodiesel puede incrementar dramáticamente la demanda de etanol en el mercado. Este artículo trata acerca de las reales posibilidades y limitaciones de la producción de biocombustibles en los países productores de azúcar desde el punto de vista tecnológico y socio-económico.
OPTIMISATION OF FRUCTOOLIGOSACCHARIDES (FOS) PRODUCTION USING BOTH INTRACELLULAR AND EXTRACELLULAR FRUCTOSYLTRANSFERASE (FT-ASE) PRODUCED BY ASPERGILLUS sp. ISOLATED FROM AN INDONESIAN SUGAR FACTORY

By

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KEYWORDS: Fructosyltransferase, Fructooligosaccharide, Extracellular, Intracellular.

Abstract

FRUCTOOLIGOSACCHARIDES (FOS) were produced from sucrose with a number of desirable characteristics such as low calories, non-carcinogenic effect, safe for diabetics, and having bifidus-stimulating functionality. Aspergillus sp. isolated from the Wonolongan Sugar Mill area in Indonesia was a potential isolate for FOS production. The aim of our research was to determine the optimum condition for conversion of sucrose to FOS using both intracellular and extracellular FT-ase of Aspergillus sp. Wet cells were used as a source of intracellular FT-ase while extracellular FT-ase consisted of crude FT-ase (broth medium) and semi pure FT-ase. Semi pure FT-ase was FT-ase in broth medium after isolation using ethanol 60% (v/v) and diluted back to the initial volume of broth medium using buffer pH 7. The effect of varying pH from 3–7, varying concentration of extracellular FT-ase, varying concentrations of wet cells and varying incubation times were tested in this experiment. All reactions for FOS production were conducted at 50°C containing sucrose 40% (w/v) as a substrate in the enzymatic reaction. Results showed that the optimum pH for FOS production was 7, both for intracellular and extracellular FT-ase. The optimum condition for FOS production using intracellular FT-ase was 2 g wet cells /100 mL substrate followed by 4 h incubation, and FOS yield reached 39.1% of the initial sucrose concentration. The optimum condition for FOS production using crude extracellular FT-ase was 1.5 times dilution using buffer pH 7 followed by 8 h incubation time and FOS yield reached 29.1%. The optimum condition for FOS production using semi-pure extracellular FT-ase was stock semi-pure FT-ase without any dilution followed by 8 h incubation and FOS yield reached 25.2%. This experiment showed that both intracellular and extracellular FT-ase of Aspergillus sp. could be used for FOS production.

Introduction

Fructooligosaccharides (FOS) is a prebiotic which is composed mainly of 1-kestose (GF2), nystose (GF3) and fructofuranosyl nystose (GF4). Industrial scale for FOS production is done mainly using fungal enzymes. Indonesian Sugar Research Institute (ISRI) has isolated Aspergillus sp. from a sugar mill area in Indonesia for FOS production namely Aspergillus sp. FOS-1(ISRI). Fermentation has been optimised for producing FT-ase in flask fermentation. Fermentation broth as a source of crude FT-ase was used for conversion of sucrose to FOS (Toharisman et al., 2008). The objective of this research project was to determine the optimum conditions for conversion of sucrose to FOS using both intracellular and extracellular FT-ase of Aspergillus sp. FOS-1(ISRI).
Materials and methods

Cultivation conditions

Fermentation using *Aspergillus sp. FOS-1(ISRI)* was conducted in a 15 litre fermentor filled with 10 litres of fermentation medium. The composition of the fermentation medium was the same as the previous experiment (Toharisman *et al.*, 2008). Fermentation was conducted at 30°C for 24 hours. pH was controlled at 7.0 with aeration 1.0vvm and agitation 100 rpm. At the end of fermentation, the broth was separated from the fungal cells by filtration. Wet cells were used as a source of intracellular FT-ase while extracellular FT-ase consisted of crude FT-ase (broth medium) and semi-pure FT-ase. Semi-pure FT-ase was FT-ase in broth medium after isolation using ethanol 60% (v/v) and diluted back to the initial volume of broth medium using buffer pH 7. FOS concentration was determined using HPLC as in the previous experiment (Toharisman *et al.*, 2008).

Effect of pH on the conversion of sucrose to FOS

Effect of pH on the conversion of sucrose to FOS was conducted only for intracellular enzyme, while the optimum condition for conversion using extracellular FT-ase was determined in the previous experiment (Toharisman *et al.*, 2008). Two grams of wet cells were added to the buffer containing 40% sucrose with pH between 3 and 7. Cells in buffer with various pH were incubated at 50°C for 1 hour.

Conversion of sucrose to FOS using intracellular and extracellular FT-ase

All reactions for FOS production were conducted in buffer pH 7 containing sucrose 40% (w/v) as a substrate for 8 hours at 50°C. Crude enzyme and semi-pure enzyme were diluted with buffer pH 7. Ratios of crude enzyme to buffer pH 7 (v/v) were various at 1:2, 2:1, and one treatment without dilution. Cells of *Aspergillus sp.* were added in buffer pH 7 containing 40% sucrose, at various cell concentrations i.e. 2, 4 and 8% (w/v).

Results and discussion

Table 1 shows the effect of various pHs on conversion of sucrose to FOS using wet cells of *Aspergillus sp. FOS-1(ISRI)* as a source of intracellular enzyme. Optimum pH for conversion was pH 7. There was no FOS synthesised on reaction between pH 3–5; on the other hand, invertase enzyme or hydrolytic enzyme was active in that pH range. Fernandez *et al.* (2004) reported a similar result that the hydrolytic activity of *Aspergillus* sp 27H isolated from soil was highest at low pH (pH 4). The optimum pH of intracellular enzyme was the same as the optimum pH of extracellular enzyme (Toharisman *et al.*, 2008).

**Table 1**—Effect of various pH on the carbohydrate composition after enzymatic reaction using wet cells of *Aspergillus sp. FOS-1(ISRI)* with sucrose as a substrate.

<table>
<thead>
<tr>
<th>pH</th>
<th>Glucose + fructose</th>
<th>Sucrose</th>
<th>Kestose</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>0</td>
<td>0</td>
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<td>26.4</td>
</tr>
<tr>
<td>7</td>
<td>31</td>
<td>20.4</td>
<td>48.5</td>
</tr>
</tbody>
</table>

Figure 1 shows the effect of various concentrations of wet cells on FOS production after incubation for 8 hours. The results showed that the highest FOS production was 2 g wet cells/100 mL substrate followed by 4 h incubation time, and FOS yield reached 39.1% of the initial sucrose concentration. The higher concentration of wet cells on the conversion reaction resulted in
the faster degradation of FOS during the long incubation time. It indicated that wet cells of *Aspergillus sp. FOS-1 (ISRI)* contained not only FT-ase, which produced FOS from sucrose, but also had a hydrolysing enzyme capable of hydrolysing FOS. However, in this experiment when the enzymatic reaction was conducted at optimum condition, high concentration of FOS was still produced. Others have reported that pellets of *Aspergillus oryzae* CFR 202 could be reused for six recycles. *Aspergillus sp. FOS-1 (ISRI)* was tested only for three recycles with consistent results.

Figure 2 shows the effect of various concentrations of crude enzyme on FOS production. The optimum condition for FOS production using crude extracellular FT-ase was 1.5 times dilution using buffer pH 7 followed by 8 h incubation time, and FOS yield reached 29.1%. The longer incubation time resulted in a higher concentration of FOS produced, except for crude enzyme without any dilution. This profile was different to the conversion using wet cells. It seemed that the activity of the hydrolysing enzyme on the enzymatic reaction using crude enzyme was not as high as its activity on the conversion process using wet cells.

![Fig. 1—Effect of various concentrations of wet cells on FOS production.](image1)

![Fig. 2—Effect of various concentrations of crude enzyme on FOS production.](image2)
Semi-pure FT-ase was prepared by isolation using ethanol 60% (v/v) and diluted back to the initial volume of broth medium using buffer pH 7. Smith and Luenser (1982) also reported the possibility of isolating FT-ase from black yeast *Aureobasidium pullulans* by water-soluble organic solvent. Figure 3 shows the effect of various concentrations of semi-pure FT-ase on FOS production.

The optimum condition for FOS production using semi-pure extracellular FT-ase was stock semi-pure FT-ase without any dilution followed by 8 h incubation and FOS yield reached 25.2%. FOS syrup produced using semi-pure FT-ase was free from residual compounds previously present in the fermentation broth medium.

**Conclusions**

FOS can be produced using both intracellular and extracellular FT-ase enzyme from *Aspergillus sp. FOS-1 (ISRI)*. So far the highest yields of FOS resulting from enzymatic reaction using intracellular FT-ase enzyme, crude extracellular FT-ase and semi-pure extracellular FT-ase were 39.1, 29.1 and 25.2% (w/w of initial sucrose concentration) respectively.

**REFERENCES**


OPTIMISATION DE LA PRODUCTION DE FRUCTOOLIGOSACCHARIDES (FOS) A L’AIDE DE FRUCTOSYLTRANSFERASE (FT-ASE), INTRA ET EXTRA CELLULAIRE PRODUITE PAR Aspergillus spp. ISOLEE DANS UNE SUCRERIE EN INDONESIE

Par

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MOTS-CLÉS: Fructosyltransferase, Fructooligosaccharide, Extracellulaire, Intracellulaire.

DES FRUCTOOLIGOSACCHARIDES (FOS) ont été produites à partir de saccharose avec un certain nombre de caractéristiques intéressantes telles que peu de calories, effet non cancérogène, sans danger pour diabétiques et ayant une fonctionnalités bifidus stimulante. Un isolat d'Aspergillus trouvé dans l’usine sucrière de Wonolongan en Indonésie s’est avéré avoir un potentiel pour la production de FOS. Le but de notre recherche était de déterminer la condition optimale pour la conversion de saccharose en FOS à l'aide de fructosyltransferase intracellulaire et extracellulaire provenant de cet isolat d'Aspergillus. Des cellules en milieu liquide ont été utilisées comme source de FT-ase intracellulaire tandis la FT-ase extracellulaire provenait d’un milieu de culture brut et aussi de la FT-ase semi purifiée. La FT-ase semi purifiée provenait d’un bouillon de culture après précipitation à l'aide d'éthanol à 60% (v/v) et dilués au volume initial du bouillon de support à l'aide de solution tampon de pH 7. Les effets de varier le pH de 3 à 7, des concentrations variées de FT-ase extracellulaire de différents niveaux provenant de différentes concentrations des cellules en milieu liquide et une gamme de période d'incubation ont été évalués dans cette étude. Toutes les réactions pour la production de FOS ont été menées à 50°C dans un substrat de saccharose à 40% (p/v) pour la réaction enzymatique. Les résultats ont démontré que le pH optimal pour la production de FOS était de 7 pour la FT-ase intracellulaire comme extracellulaire. La condition optimale pour la production de FOS à l'aide de FT-ase intracellulaire était de 2 g de cellules pour 100 ml de substrat en milieu liquide pour une période d'incubation de 4 h ce qui résultat en un rendement de FOS à 39.1% de la concentration initiale en saccharose. La condition optimale pour la production de FOS à l'aide de la FT-ase extracellulaire à l'état brut, était une dilution de 1.5 à l'aide du tampon de pH 7 suivi par une période d'incubation de 8 h ce qui mena à un rendement de FOS atteignant 29.1%. La condition optimale pour la production de FOS à l'aide de la FT-ase extra cellulaire semi-purifiée était l’utilisation de la solution stock sans dilution pour une période d'incubation de 8 h ce qui donna un rendement de FOS de l’ordre de 25.2 %. Cette expérimentation a démontré que la FT-ase intracellulaire et extracellulaire provenant d’une espèce Aspergillus pouvait être utilisée pour la production de FOS.
OPTIMIZACIÓN DE LA PRODUCCIÓN DE FRUCTOOLIGOSACÁRIDOS (FOS), USANDO TANTO FRUCTOSILTRANFERASA (FT-ASA) INTRA Y EXTRA CELULAR, PRODUCIDA POR ASPERGILLUS sp. AISLADOS EN UNA FÁBRICA DE AZÚCAR INDONESIA

Por

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PALABRAS CLAVE: Fructosiltransferasa, Fructooligosacárido, Extracelular, Intracellular.

Resumen

LOS FRUCTOOLIGOSACÁRIDOS (FOS) fueron producidos a partir de sacarosa con un conjunto mde características deseables tales como, bajas calorías, sin efectos cancerígenos, seguros para diabéticos y con funcionalidad bifido estimulante. El Aspergillus sp para la producción de FOS fue aislado en áreas del Central Wonolongan en Indonesia. El propósito de nuestra investigación era determinar las condiciones óptimas de conversión de la sacarosa en FOS, usando tanto la FT-asa intra y extracelular del Aspergillus sp. Se utilizó pasta de levadura como fuente de FT-asa intracelular, mientras la FT-asa extracelular consistió en FT-asa cruda (medio de cultivo) y FT-asa semipura. La Ft-asa semipura fue la FT-asa del medio de cultivo después de ser aislada usando etanol al 60% w/v y diluida de nuevo al volumen del medio de cultivo con solución buffer pH 7. En este experimento se probó el efecto de variar el pH de 3–7, variando la concentración de FT-asa extracelular, variado la concentración de la pasta de levadura y el tiempo de incubación. Todas las reacciones para la producción de FOS se realizaron a 50°C, conteniendo sacarosa al 40% (w/v) como sustrato en la reacción enzimática. Los resultados mostraron que el pH óptimo para la producción de FOS era 7, tanto para ft-asa intra como extra celular. La condición óptima para la producción de FOS empleando FT-asa intracelular fue de 2 g de pasta de levadura/ml de sustrato, con 4 horas de incubación y el rendimiento de FOS alcanzó 1% de la concentración inicial de sacarosa. La condición óptima para la producción de FOS empleando FT-asa cruda extracelular fue con dilución 1.5 veces empleando buffer a pH 7, seguida de 8 horas de incubación y el rendimiento de FOS alcanzó 29.1%. La condición óptima para la producción de FOS usando FT-asa extracelular semipura fue conservar la Ft-asa semipura sin dilución, seguida de 8 horas de incubación y el rendimiento de FOS alcanzó 25.25. Este experimento mostró que tanto la FT-asa intra como extracelular del Aspergillus sp podían ser empleadas en al producción de FOS.
DIVERSIFYING SUGAR CANE: CELLULOSE FROM BAGASSE

By

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KEYWORDS: Sugarcane, Bagasse, Cellulose, Diversification.

Abstract

CANE SUGAR industries are going through severe economical crises. To increase profitability, they must use every product or by-product of cane. As an example of diversifying potential, ethanol and cellulose, both obtained from bagasse, are compared. In Mexico, bio-ethanol is worth around US$0.45 per litre, and about 200 litres can be obtained per tonne of dry bagasse. Non-treated dry bagasse contains 51.67% cellulose, 24.42% hemicelluloses, 10.23% soluble and 13.68% lignin. Thus, theoretically, 516.7 kg of cellulose can be obtained per tonne of bagasse. Whitened cellulose in México is MX$4.50 to MX$5.00 (US$0.30 to US$0.33) per kg. Comparing bio-ethanol and cellulose revenue: ethanol is MX$1200 (US$80.00) vs. cellulose MX$2583.50 (US$172.20) per tonne of dry bagasse. Possible cellulose production from Mexican sugarcane (2007–2008): milled cane 46 518 988 t; dry bagasse 6 977 848 t; yielding 3 605 454 t cellulose. Presently Mexico imports 80% of required cellulose. Not all cellulose fibres from bagasse can be efficiently used as fuel. With the new technology developed and tested by us, all long fibres can be converted into cellulose, and 94% of pith can be burnt. However, auxiliary fuel (3.9 litres of heavy bunker C per milled tonne of cane) is also required. It is important to establish laboratory methods to determine the real content of fibre convertible to cellulose and how biotechnology can help improve the quantity and quality of cellulose. These tests are to be performed at industrial laboratories and in accordance with official procedures.

Introduction

World sugar consumption is continuously increasing (Figure 1). However, a more detailed study of per capita consumption reveals cane and beet sugar consumption have decreased since 1980, when the corn sweetener (a composite of fructose, glucose and dextrose obtained from corn) replaced sucrose to some extent, Figure 2 (Jensen, 2005).

The sugar market is also affected by the instability of world market prices for sweeteners.

These facts resulted in severe economical crises for cane sugar industries, forcing them to look for new and alternative technologies and products to compensate for market price instability and per capita consumption decrease.
A typical flow diagram of a cane sugar factory is shown in Figure 3. There are various by-products in the process but only one commercial product, which is sugar; also, in some cases, alcohol. In order to improve the profitability of the sugar industry, by-products can become commercially feasible by applying new technologies or even by converting them to new products.

Diversifying options will be selected by each sugar mill. Local market and exporting opportunities are the factors to be considered.

The following 3 scenarios show and compare different uses of by-products: actual situation, conversion of all bagasse to ethanol, and cellulose production from bagasse.
Diversification options

There are various options for commercial utilisation of almost all the by-products in the sugarcane process. Some of them are still in a research and development stage, others need new technologies to be competitive, while others are used only in some countries.

Bagasse

Bagasse is the residue from sugarcane milling after the juice has been expressed from the crushed cane stalk. Average composition: 50% cellulose, 30% hemicelluloses and 20% lignin. Actual applications are:

1. Fuel in the sugar process. 91% of energy required in Mexican sugar mills is obtained from bagasse combustion, super heated steam generates electricity, and exhaust steam is used in the sugar process.
2. Cattle feed. Some communities are incorporating bagasse into the diet of different livestock, like cattle and chickens; reports and studies conclude no negative effect in the growth of the animals.
3. Paper and fibre board manufacturing. The old process used in industry to obtain cellulose from cane bagasse requires the chemical delignification and bleaching of the resulting paper pulp, being dangerous for health and environment; uses NaOH and chlorine (Hurter, 2001). A new biotechnology process is being developed by Mexican researchers, so that cellulose can be obtained from bagasse using some filamentous fungi species which are able to produce enzymes that can destroy the lignin and convert it to cellulose.
4. Biodegradable tableware. In China, some disposable tableware from bagasse is produced, replacing plastic or virgin paper. Tableware so produced has no plastic or wax lining applied and can be used for both hot and cold items.
5. As dye removal. Bagasse can be used for the removal of azo dyes by adsorption (Liew et al., 2005).
6. Dietary fibre. There is an industry in the United States selling milled and treated bagasse for use as an additive for human food, for thickening soups, for increasing the fibre content, and to improve the consistency of some precooked meals.

**Leaves**

In some countries, the leaves are still burnt in the field after harvesting, without any energy recovery. It is possible to burn leaves in the sugar mills’ boilers.

**Filter cake**

Used as fertiliser in the cane fields; for improving its effectiveness, some biochemical treatment and earthworms can be applied.

**Molasses**

Molasses contains sugar that can be used as a carbon source substrate for different biotechnology processes: citric acid (Garg and Sharma, 1991), acetic acid, ethanol, etc.; development of these technologies is in process around the world.

**Cases studies**

Comparing three different alternatives using bagasse, results are shown in Table 1:

1) Burning 100% bagasse in boilers (present situation)
2) Convert all obtained bagasse to ethanol, burning diesel and/or bunker C as fuel and
3) Convert all obtained bagasse to cellulose, burning diesel and/or bunker C as fuel.

Considered yields: 1.18 kilograms of dry bagasse per kg of sugar; 200 litres of EtOH per tonne of dry bagasse, 0.4 kg of cellulose per kg of dry bagasse; cellulose recovery efficiency considered to be 80%.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>By-product</strong></td>
<td>None</td>
<td>Ethanol</td>
<td>Cellulose</td>
</tr>
<tr>
<td>% burned bagasse</td>
<td>100 %</td>
<td>0 %</td>
<td>0 %</td>
</tr>
<tr>
<td><strong>Fuel need, litre/kg sugar</strong></td>
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<td>36.6</td>
</tr>
<tr>
<td><strong>Fuel cost, USD/litre</strong></td>
<td>0.395</td>
<td>0.395</td>
<td>0.395</td>
</tr>
<tr>
<td><strong>Specific fuel cost, USD/kg sugar</strong></td>
<td>0.017</td>
<td>0.126</td>
<td>0.126</td>
</tr>
<tr>
<td><strong>Dry bagasse, kg/kg sugar</strong></td>
<td>1.277</td>
<td>1.277</td>
<td>1.277</td>
</tr>
<tr>
<td><strong>EtOH obtainable, litre/kg sugar</strong></td>
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<td></td>
<td></td>
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<tr>
<td><strong>EtOH price, USD/litre</strong></td>
<td>0.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>EtOH obtainable, USD/kg sugar</strong></td>
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<td></td>
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<tr>
<td><strong>Cellulose obtainable, kg/kg sugar</strong></td>
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<td>0.511</td>
<td></td>
</tr>
<tr>
<td><strong>Bleached cellulose price, USD/kg</strong></td>
<td></td>
<td>0.33</td>
<td></td>
</tr>
<tr>
<td><strong>Cellulose obtainable, USD/kg sugar</strong></td>
<td></td>
<td>0.169</td>
<td></td>
</tr>
<tr>
<td><strong>Profit (loss) USD/kg sugar</strong></td>
<td>(0.017)</td>
<td>(0.012)</td>
<td>0.042</td>
</tr>
</tbody>
</table>

**Conclusions**

Commercial by-product utilisation is a very interesting alternative; much care should be taken to diminish risks when investing.

New technologies are a good opportunity, as by-products can achieve very high values, allowing the mills to increase sales and revenues. As a major labour generator, all alternatives are to be taken after a thorough analysis.

Even with high ethanol prices, cellulose applications are far more profitable.
REFERENCES


DIVERSIFICATION DE LA CANNE A SUCRE: PRODUCTION DE CELLULOSE A PARTIR DE LA BAGASSE

Par

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MOTS-CLÉS: Canne à Sucre, Bagasse, Cellulose, Diversification.

Résumé

Les industries cannières font face à des crises financières aiguës. Pour augmenter leur profitabilité, elles doivent utiliser chacun des produits ou sous-produits de la canne. Comme un exemple du potentiel de diversification, une comparaison est faite entre l'éthanol et la cellulose. Au Mexique, le bioéthanol est évalué à 45 centimes américains le litre et quelques 200 litres sont obtenus d'une tonne de bagasse sechée. La bagasse sèche non traitée contient 51.67% de cellulose, 24.42% de hémicelluloses, 10.23% de produits soluble et 13.68% de lignine. Ainsi, théoriquement 516.7 kg de cellulose peuvent être produits d'une tonne de bagasse. La cellulose purifiée vaut au Mexique 4.50 à 5.00 dollars mexicains ou 30 à 33 centimes américains le kilo. En comparant les revenus de la cellulose et l'éthanol, on s'aperçoit que l'éthanol rapporte 1200 dollars mexicains ou 80.00 dollars américains par tonne de bagasse sechée contre 2583.50 dollars mexicains ou 172.20 de dollars américains pour la cellulose. La production potentielle de cellulose en 2007/08 au Mexique était de 3 605 454 tonnes à partir de 46 518 998 tonnes de canne et 6 977 848 tonnes de bagasse. Actuellement le Mexique importe 80% de ses besoins en cellulose. Pas toutes les fibres de cellulose de la bagasse peuvent être utilisées comme combustible. En ayant recours à la nouvelle technologie développée et évaluée par nos soins, toutes les longues fibres peuvent être converties en cellulose et 94% de la moelle peuvent être brulées. Toutefois un apport extérieur de fioul de l'ordre de 3.9 litres d'huile lourde est nécessaire par tonne de canne usinée. Il est important de mettre au point des procédés de laboratoire capables de déterminer la teneur réelle de fibre susceptible d'être convertie en cellulose et comment la biotechnologie pourrait aider à améliorer la quantité et qualité de cette cellulose. Ces procédés doivent être conduits dans des laboratoires industriels et selon les méthodes officiellement acceptées.
DIVERSIFICANDO LA CAÑA DE AZÚCAR: CELULOSA DEL BAGAZO

Por

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PALABRAS CLAVE: Caña de Azúcar,
Bagazo, Celulosa, Diversificación.

Resumen

La industria de la caña de azúcar atraviesa una severa crisis económica. Para incrementar su viabilidad económica debe utilizar cada producto ó sub producto de la caña. Como un ejemplo del potencial diversificador se comparan el etanol y la celulosa, ambos obtenidos del bagazo. En México el bioetanol cuesta acreedor de US$ 0.45 por litro y cerca de 200 litros pueden obtenerse por tonelada de bagazo seco. El bagazo seco no tratado contiene 51.67% de celulosa, 24.42% de hemicelulosa, 10.23% de solubles y 13.68% de lignina. Por tanto, teóricamente, 516.7 kg de celulosa pueden obtenerse por tonelada de bagazo seco. La celulosa blanqueada cuesta Mx 4.50 a Mx 5.00 (US$ 0.30 a US$ 0.33) por kg. Comparando los ingresos del bioetanol y la celulosa, el etanol vale Mx 1200 (US$ 80.00) vs. la celulosa a Mx 2583 (US$172.20) por tonelada de bagazo seco. La producción posible de celulosa de la caña de azúcar mexicana (2007–2008) es: caña molida 46 518 988 t, bagazo seco 6 977 848 t, rindiendo3 605 454 t de celulosa. En la actualidad México importa el 80% de la celulosa que requiere. No toda la fibra celulósica del bagazo puede ser utilizada eficientemente como combustible. Con la nueva tecnología desarrollada y comprobada por nosotros, toda la fibra larga puede ser convertida en celulosa y el 945 del bagacillo puede quemarse. Sin embargo, se requiere combustible adicional (3.9 litros de Bunker C pesado por t de caña molida).
**MAHANARVA FIMBRIOLATA INFESTATION IN SUGARCANE: IMPACTS ON ETHANOL PRODUCTION**

By


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KEYWORDS: *Saccharum* spp., Spittlebug, Cane Quality, Ethanolic Fermentation.

**Abstract**

The spittlebug (*Mahanarva fimbriolata*) has become an important pest of sugarcane in Brazil, causing stalk yield and cane quality losses. This research was conducted to evaluate the effects of spittlebug damage levels on ethanol production. The experiment was set in a sugarcane field with no trash burn, using the variety SP80-1842 (4th ratoon), four stalk damage levels (0, 15%, 30% and 60%) and two harvest dates (May/June and October). Batch fermentation was conducted with baker’s yeast, *Saccharomyces cerevisiae*, with 10 fermentation cycles. There was a reduction in juice sucrose content, total reducing sugars, purity and pH and an increase in total juice and volatile acidity. It was also observed that pest attack damage in sugarcane negatively influenced the fermentation process, with higher levels of acidity and residual reducing sugars and lower alcohol content in wines. Distillates presented higher acetaldehyde and lower ethanol concentration with increasing spittlebug stalk damage levels.

**Introduction**

The spittlebug *Mahanarva fimbriolata* (Stal, 1854) (Hemiptera: Cercopidae) has become a key pest of sugarcane in Brazil, because of the conditions resulting from mechanical harvesting with no trash burn. Nymphs suck roots resulting in nutrient deficiency and dry stalks, affecting both stalk and sugar yield.

Metabolic alterations take place in sugarcane in response to spittlebug infestation, producing a wide variety of biomolecules, which interfere with cane quality and processing, yeast metabolism inhibition during fermentative process, and alcoholic yield losses (Ravaneli *et al.*, 2006).

The damages may be severe on most genotypes, especially in middle and end-of-season varieties (Dinardo-Miranda *et al.*, 1999).

This research was conducted to determine the effects of *M. fimbriolata* damage levels in sugarcane on cane quality and on ethanol production.

**Materials and methods**

The variety used was SP 80-1842 (4th ratoon). The mean infestation observed was 5.32 nymphs/m. Cane was harvested at the end of the rainy season (May/June) and after the dry season (October). The stalk damage levels (15%, 30% and 60%) were compared to uninfested control (Gonçalves *et al.*, 2003).

Juice extraction was performed as described by Tanimoto (1964). Total soluble solids (T.S.S.) and sucrose content analyses were performed as recommended by Schneider (1979); pH, total Reducing Sugars (T.R.S) through Lane & Eynon’s (1934) method; Total Acidity by juice titration with NaOH 0.05N, Volatile Acidity as indicated by Vilella *et al.* (1973) and Total Phenolic Compounds through Folín and Ciocalteau’s (1927) colorimetric protocol.
To conduct ethanolic fermentation, juice was submitted to a clarification process. In the first harvest date, juice purity was diluted to 13° Brix. In the second harvest time, juice purity was diluted to 14° Brix, and pH 3.5 (± 0.3). Fresh baker’s yeast (Saccharomyces cerevisiae) was used at a concentration of 30g per liter of must. Batch fermentations were conducted in 1 L erlenmeyers, in a BOD incubator set at 32°C, monitoring the process with the help of a Brix densimeter. Ten fermentative cycles were conducted. Total residual reducing sugars (T.R.R.S.) (Lane and Eynon, 1934) and alcohol content were determined in wines. The distillates were submitted to volatile compounds analyses by gas chromatography.

**Statistical analyses**

For juice analyses, the experiment was arranged in a completely randomised design in a 4 x 2 factorial. Treatments corresponded to the spittlebug stalk damage levels (0, 15%, 30% and 60%) and harvesting times (May/June and October/2007). Analyses were performed in fifteen replications.

Wine and distillate data were analysed in completely randomised design in a 4 x 10 x 2 factorial. Treatments corresponded to the spittlebug stalk damage levels, fermentative cycles and harvesting times. Analyses were performed in three replications. Data were submitted to an ANOVA, and means were compared by Tukey test at 5%.

**Results and discussion**

*M. fimbriolata* infestation levels affected cane quality. Sucrose content, T.R.S. and juice purity were lower at higher damage levels. Losses were 8.76%, 3.14% and 6.95%, respectively (Table 1).

As spittlebugs attack sugarcane roots, limiting water, nutrient uptake, photosynthesis is expected to be affected, reducing sucrose accumulation (Dinardo-Miranda *et al.*, 2002; Ravaneli *et al.*, 2006). In addition, the reduction in sucrose levels may be a consequence of the biosynthesis of plant defence compounds, such as phenols (Buchanan *et al.*, 2000) and the attempt to produce new vegetative parts. Juice pH, total and volatile acidity were also affected by higher damage levels (Table 1), which indicates that cane was in a deterioration process.

**Table 1**—Effects of *Mahanarva fimbriolata* damage levels on technological parameters of sugarcane juice.

<table>
<thead>
<tr>
<th>Damage levels (A)</th>
<th>TSS %</th>
<th>Sucrose gH₂SO₄/L</th>
<th>Purity</th>
<th>TRS 5.27A</th>
<th>pH 1.09B</th>
<th>Total acidity 13.53B</th>
<th>Volatile acidity 18.76A</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>20.16A</td>
<td>17.33A</td>
<td>85.41A</td>
<td>18.66A</td>
<td>5.27A</td>
<td>1.09B</td>
<td>13.53B</td>
</tr>
<tr>
<td>15%</td>
<td>20.04A</td>
<td>17.15A</td>
<td>85.16A</td>
<td>18.38AB</td>
<td>5.26AB</td>
<td>1.13AB</td>
<td>15.52AB</td>
</tr>
<tr>
<td>30%</td>
<td>19.86A</td>
<td>16.78A</td>
<td>84.11AB</td>
<td>17.96B</td>
<td>5.20B</td>
<td>1.19AB</td>
<td>17.14AB</td>
</tr>
<tr>
<td>60%</td>
<td>19.06B</td>
<td>15.89B</td>
<td>82.66B</td>
<td>17.39C</td>
<td>5.09C</td>
<td>1.25A</td>
<td>18.76A</td>
</tr>
<tr>
<td>F test</td>
<td>5.46**</td>
<td>11.50**</td>
<td>5.06**</td>
<td>13.97**</td>
<td>18.84**</td>
<td>4.45**</td>
<td>3.62**</td>
</tr>
<tr>
<td>F test LSD (Tukey)</td>
<td>0.78</td>
<td>0.7</td>
<td>2.0</td>
<td>0.55</td>
<td>0.07</td>
<td>0.12</td>
<td>4.34</td>
</tr>
<tr>
<td>Harvest times (B)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>May/June</td>
<td>15.23B</td>
<td>11.96B</td>
<td>79.41B</td>
<td>12.97B</td>
<td>5.26A</td>
<td>1.23A</td>
<td>19.23A</td>
</tr>
<tr>
<td>October</td>
<td>24.33A</td>
<td>21.61A</td>
<td>89.26A</td>
<td>23.22A</td>
<td>5.15B</td>
<td>1.11B</td>
<td>13.25B</td>
</tr>
<tr>
<td>F test</td>
<td>1841.07**</td>
<td>2596.62**</td>
<td>315.12**</td>
<td>4743.77**</td>
<td>30.11**</td>
<td>13.81**</td>
<td>25.84**</td>
</tr>
<tr>
<td>F test LSD (Tukey)</td>
<td>0.42</td>
<td>0.37</td>
<td>1.09</td>
<td>0.29</td>
<td>0.04</td>
<td>0.06</td>
<td>2.33</td>
</tr>
<tr>
<td>F test A x B</td>
<td>0.18ns</td>
<td>0.19ns</td>
<td>1.01ns</td>
<td>1.99ns</td>
<td>8.28**</td>
<td>2.56ns</td>
<td>0.05ns</td>
</tr>
<tr>
<td>CV</td>
<td>5.87</td>
<td>6.18</td>
<td>3.6</td>
<td>4.5</td>
<td>2.02</td>
<td>15.11</td>
<td>39.66</td>
</tr>
</tbody>
</table>

ns = non-significant; * = significant at 5% probability; ** = significant at 1% probability.
The damage levels of *M. fimbriolata* resulted in higher levels of total residual reducing sugars in the wine, reflected in alcohol yield decrease (Figure 1). The highest T.R.R.S. levels were found in the October harvest. This behaviour may be occurring as a result of yeast stress because of cane quality, which presents high levels of acidity and phenolic compounds (data not shown).

There were losses of 13.82% in alcohol content in wines at higher damage levels (Figure 1). Similar results were described in Ravaneli et al. (2006), which observed reduction of 7.2% in alcohol content when spittlebug infestation levels were higher than 2.5 nymphs/m. In distillates, there was higher acetaldehyde concentration when infested cane stalks were used. This behaviour is evident in the October harvest, although the highest means were found in the first harvesting season (Figure 2).

The opposite was observed in ethanol levels (Figure 2), which corroborates the juice quality results. Also, acetaldehyde levels indicate that the fermentation process itself may have been affected, because acetaldehydes are precursors to ethanol in the fermentation pathway. Therefore, *M. fimbriolata* attack results in incomplete fermentations because it affects cane quality and the fermentation process.

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**Figure 1**—Effect of *M. fimbriolata* damage levels on residual reducing sugars (T.R.R.S.) and alcohol content in wines.

**Figure 2**—Effect of *M. fimbriolata* damage levels on acetaldehyde and ethanol contents in distillates.
Acknowledgements

The authors are thankful to Louis Dreyfus Bioenergy Commodities - Usina São Carlos, for providing the sugarcane and for their help with conduct of the experiment, and FAPESP (process 2006/03005-0 and 2006/03006-6) for financial support. We also thank Eduardo Rossini Guimarães for his helpful suggestions and critical review of the manuscript.

REFERENCES


L’IMPACT D’UNE INFESTATION DE MAHANARVA FIMBRIOLATA SUR LA PRODUCTION D’ETHANOL

Par
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MOTS-CLÉS: Saccharum spp., Cercoped, Qualité de la Canne à Sucre, Fermentation d’Éthanol.

Résumé
MAHANARVA FIMBRIOLATA de la famille des Cercopidae, est devenu un ravageur important de la canne à sucre au Brésil, où il induit des pertes de rendements et de qualité. Cette étude a été réalisée pour évaluer les effets de différents niveaux d’infestations de Mahanarva fimbriolata sur la production d’éthanol. L’expérience a été réalisée dans un champ de canne à sucre sans brûlis, avec la variété SP80-1842 (4ème repousse), quatre niveaux de dommage des tiges (0, 15 %, 30 % et 60 %) et deux dates de récolte (mai / juin et octobre). Des fermentations en discontinues ont été menées avec de la levure boulángère, Saccharomyces cerevisiae, avec 10 cycles de fermentation. Il y avait une réduction de la teneur en saccharose du jus, des sucres réducteurs, de la pureté, du pH et une augmentation en jus total et des acides volatils. Il a également été observé que les dommages causés par l’infestation du ravageur ont une influence négative sur le processus de fermentation, avec des niveaux plus élevés de l’acidité ; des sucres réducteurs résiduels et une plus faible teneur en alcool dans les vins. Les distillats présentaient une plus forte concentration en acétaldéhyde et une plus faible concentration en éthanol, pour des dommages de niveaux croissants.

INFECCIÓN POR MAHANARVA FIMBRIOLATA EN LA CANA DE AZÚCAR: IMPACTO EN LA PRODUCCIÓN DE ETANOL

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PALABRAS CLAVE: Saccharum sp., Spittlebug, Calidad de Caña, Fermentación Etanolica.

Resumen
EL SPITTLEBUG (Mahanarva fimbriolata) se ha convertido en una importante plaga de la cana de azúcar en Brasil, provocando pérdidas en el rendimiento de tallos de cana y en la calidad de la caña. Esta investigación se realizó para evaluar los efectos de los niveles del daño de este insecto en la producción de etanol. El experimento se localizó en un campo de caña sin quema de la paja, usando la variedad SP 80-1842 (4º retoño), cuatro niveles de daño en los tallos (0, 15%, 30% y 60%) y dos fechas de cosecha (Mayo/Junio y Octubre). Se realizaron fermentaciones en batch empleando levadura de panificación, Saccharomyces cerevisiae, con 10 ciclos de fermentación. Hubo una reducción en el contenido de sacarosa del jugo, en los azúcares reductores totales, la pureza y el pH, y un incremento en el jugo total y la acidez volátil. Se observó también que los daños por el ataque de la plaga en la caña de azúcar influye negativamente el proceso fermentativo, con más altos niveles de acidez y azúcares reductores residuales, así como menores contenidos de alcohol en los vinos. Los destilados presentan mayores aldehídos y menores concentraciones de etanol con el incremento de los daños de la plaga en los tallos de caña.
RHEOLOGICAL BEHAVIOUR OF VINASSES FROM A MEXICAN BIOETHANOL FACTORY

By

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KEYWORDS: Rheology, Vinasses, Bioethanol, Viscoelastic, Energy Of Activation.

Abstract

THE KNOWLEDGE of the rheological behaviour of vinasses is very important for the operation and design of a sugarcane bioprocess. This study characterised rheological behaviour of residues from a bioethanol process that uses final molasses as the carbohydrate source. For this, we used a rotational rheometer Anton Paar MCR 301, concentric cylinder system, Peltier plate for temperature control and software Rheoplus for date capture. The temperature effect was compensated with an Arrhenius model, which measures the activation energy of vinasses in the range 298–310 K. The results showed an activation energy of 2.496 × 10³ Cal/g-mol, a non-Newtonian behaviour with viscoelastic characteristic, i.e. at low shear rate range (0–387 L/s) as fluid or viscous (pseudo plastic) flow. After this, there is an inflection point at high shear rate as solid or elastic flow (dilatant), because the vinasses presented a material restructure. This behaviour is due to the complex chemical composition of vinasse from final molasses, which is a by-product of the sugarcane process. To confirm this behaviour, it was compared with the rheological behaviour of vinasse from sugarcane juice as the carbon source that showed a dilatant behaviour, i.e. as a fluid flow. These results showed that, depending on the substrate chemical composition (complex/simple), similar rheological behaviour (complex/simple) is obtained.

Introduction

Residues and derivates from the sugarcane industry can be made into by products, with an economic value and avoid any environmental impact. This impact has a direct effect on the people, by particles emission, contaminant gases, solid residues or discharged fluids that affect environmental health, caused fundamentally by technological advances and low environmental education.

Vinasses from bioethanol production are classified as organic residues of main effect pollutants. From each hectolitre of ethanol produced from final molasses, 10 to 15 hectolitres of vinasse are obtained, with a Chemical Oxygen Demand-COD₅ between 60 and 70 g/L and a pH ca. 4.0. This vinasse is often discharged into rivers, booties and quays without treatment.

Rheology is a science that studies flow and deformation of material when subject to low external forces and depicts the fluids on a graph of stress strength versus shear rate, denominated rheogram (see Figures 1a and 1b). In contrast to fluid mechanics that studies how normal fluids behave, rheology shows how non-Newtonian fluids behave, i.e. that do not obey the Newton law, Equation (1) Bird et al. (2006):
\[\tau = \mu \cdot \dot{\gamma}\]  \hspace{1cm} (1)

where: \(\tau\) is a shear stress [Pa]

\(\mu\) is the dynamic viscosity [Pa·s]

\(\dot{\gamma}\) is the shear rate [sec\(^{-1}\)]

There are in industry other very complex non-Newtonian fluids such as viscoelastic fluids, located at the interface between solid and fluid behaviour.

The knowledge of the rheological behaviour of vinasses is very important to project, operate and design sugarcane bioprocesses, such as energy requirements during mixing and transport, friction losses in pipelines and accessories, and in other aspects of engineering. The rheological research gradually also finds applications in the following: kinetic reactions, chemical structures and components, concentration and distribution of molecular mass, Cantú-Lozano (1990).

**Methodology**

The vinasse samples were collected from two bioethanol factories, a Mexican and a Brazilian. The rheological characterisation was realised in an Anton Paar \(^\text{TM}\) rheometer model MCR301 with a Peltier plate for control of temperature (Figure 2). A concentric cylinder and parallel plates geometry and Rheoplus software for data capture were used with vinasse samples of 30 mL.
Rheological behavior of Mexican vinasse samples was characterised by Herschel-Bulkley model Equation (2) Morel et al. (2008)

\[ \tau = \tau_0 + K \dot{\gamma}^n \]  

where:

- \( \tau \) is a shear stress [Pa]
- \( \tau_0 \) is a yield stress [Pa]
- \( K \) is the consistence index [Pa\textbullet\text{s}^n]
- \( n \) is the rheological index [–]
- \( \dot{\gamma} \) is the shear rate [sec\(^{-1}\)]

The activation energy \((Ea)\) was calculated using the Arrhenius model equation (3), which correlates the apparent viscosity \((\eta_a)\) with temperature. In this case, vinasse samples were rotated in the rheometer at 200 rpm within a temperature range of 298–310 K.

\[ \eta_a = \eta_0 \cdot e^{\frac{E_a}{RT}} \]  

where:

- \( \eta_0 \) is initial viscosity [Pa\textbullet\text{s}]
- \( E_a \) is flow activation energy [Cal\textbullet\text{g-mol}^{-1}]
- \( R \) is ideal gases constant [Cal\textbullet\text{g-mol}^{-1}\text{K}^{-1}]
- \( T \) is absolute temperature [K]

Results

Rheological characterisation

Figure 3 shows the rheogram of behaviour of shear stress versus shear rate of a diluted Mexican vinasse sample and Table 1 shows the parameters of the Herschel Bulkley model from Mexican vinasse, performed with software Rheoplus, the values of: yield stress \( \tau_0 \) and consistency index, \( K_{HB} \), decreases with temperature increases. The flow behaviour index, \( n \), approaches Newtonian behaviour, \( i.e.\ n=1.0\).
Table 1—Parameters of Herschel Bulkley from Mexican vinasse.

<table>
<thead>
<tr>
<th>$\tau_0$ [Pa]</th>
<th>$K_{HB}$ [Pa·sec$^n$] x10$^3$</th>
<th>$N$ [-]</th>
<th>$T$ [K]</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.11177</td>
<td>1.774</td>
<td>1.1</td>
<td>293.15</td>
<td>0.99881</td>
</tr>
<tr>
<td>0.10537</td>
<td>1.68</td>
<td>1.08</td>
<td>298.15</td>
<td>0.90909</td>
</tr>
<tr>
<td>0.0998</td>
<td>1.479</td>
<td>1.05</td>
<td>303.15</td>
<td>0.99862</td>
</tr>
<tr>
<td>0.08950</td>
<td>1.392</td>
<td>1.01</td>
<td>308.15</td>
<td>0.99827</td>
</tr>
</tbody>
</table>

Viscosity comparison

In Figure 4, we present comparisons of experimental data of viscosity apparent behaviour of a concentrated sample of Mexican vinasse that uses final molasses as a carbohydrate source with a concentrated sample of Brazilian vinasse that uses sugar juice as a carbohydrate source.

The Mexican vinasse presents non-Newtonian behaviour with viscoelastic characteristics at low shear rate (0–387 sec$^{-1}$), as pseudoplastic and, after an inflection point (387–2200 sec$^{-1}$), at high shear rate as dilatant flow with tendencies of solid behaviour.

The Brazilian vinasse presents a dilatant behaviour. These results showed that, depending on substrate chemical composition (complex/simple), similar rheological behaviour (complex/simple) is obtained.

![Fig. 4—Comparison of apparent viscosities of two concentrated samples, Mexican and Brazilian vinasses](image)

Effect of temperature

The effect of temperature was investigated with the Arrhenius model, Eq. (3). Figure 5 shows its linearisation with logarithm of viscosity against temperature reciprocal absolute. Equation (4) and Table 2 present the parameters of the Arrhenius model.
Fig. 5—Linearisation of Arrhenius model.

\[ \ln \eta_{ap} = -3.0074 + 1266 \left( \frac{1}{T} \right) \quad R^2 = 0.99109 \]  

(4)

Table 2—Parameters of Arrhenius model for Mexican vinasse.

<table>
<thead>
<tr>
<th>( \eta_0 ) [Pa] ( \times 10^2 )</th>
<th>( E_a ) [Cal/g-mol]</th>
<th>( R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.942</td>
<td>2496.55</td>
<td>0.99109</td>
</tr>
</tbody>
</table>

Therefore the Arrhenius equation is defined, for these conditions, as follows:

\[ \eta_{ap} = 4.942 \times 10^{-2} Pa \cdot s \cdot e^{\frac{2496.55 \text{ Cal}/g\cdot\text{mol}}{RT}} \]  

(5)

Conclusions

The examined diluted Mexican vinasse, presents a non-Newtonian behaviour according to Herschel Bulkley model. With temperature increase, it approaches Newtonian behaviour (\( \tau_0 \to 0 \), \( n = 1.0 \) and \( K_{HB} \equiv \mu \)).

The examined concentrated Mexican vinasse presents a non-Newtonian behaviour with viscoelastic characteristic and high temperature, sensibility and shows a high Activation Energy Flow.

Depending on the chemical composition of the substrate (complex/simple), similar rheological behaviour (complex/simple) is obtained.

In a general way, Rheology of Vinasses is a useful tool to determine differences in: concentration, components and temperature sensibility.

Acknowledgment

The author Dr. Denis Cantú Lozano thanks Eng. M.A. Mancillas Rodríguez of Ingenio La Providencia S.A. de C.V. – México for useful information in this research.

REFERENCES


COMPORTEMENT RHÉOLOGIQUE DES VINASSES D'UNE DISTILLERIE DE BIOÉTHANOL AU MEXIQUE

Par

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MOTS-CLÉS: Rhéologie, Vinasses, Bioéthanol,
Viscoélasticité Énergie d'Activation.

Résumé
LA CONNAISSANCE du comportement rhéologique des vinasses est très importante pour le
l'utilisation et la conception d'un bioprocessus impliquant la canne à sucre. Cette étude a porté sur
le comportement rhéologique des résidus d'un procédé de production de bioéthanol utilisant la
mélasse finale comme source de glucides. Pour ce faire, nous avons utilisé un rhéomètre rotatif,
Anton Paar MCR 301, un système de cylindre concentrique, une plaque Peltier pour contrôler la
température et le logiciel Rheoplus pour l'acquisition des données. L'effet de température a été
compensé avec un modèle d'Arrhenius, qui mesure l'énergie d'activation de la vinasse dans une
plage de 298–310 K. Les résultats ont démontré une énergie d'activation de 2,496.10³ cal.g⁻¹.mol⁻¹,
un comportement non-Newtonien avec une caractéristique viscoélastique (c'est-à-dire à faible
cisaillement) de 0–387 L.s⁻¹ comme écoulement fluide ou visqueux (pseudo plastique). Après cela,
ous distinguons un point d'inflexion à taux élevé de cisaillement comme pour un solide ou un flux
elastique dilatant, dû à une restructuration de la vinasse. Ce comportement est dû à la composition
chimique complexe de la vinasse produite à partir de la mélasse finale, qui est un sous-produit de
l'usinage de la canne. Pour confirmer ce comportement, nous l'avons comparé avec le
comportement rhéologique de la vinasse produite à partir de jus de canne comme source de carbone,
qui a démontré un comportement dilatant, c'est-à-dire celui d’un écoulement fluide. Ces résultats
ont démontré qu’en fonction de la composition chimique du substrat (complexe ou simple), des
comportements rhéologiques similaires (complexe ou simple) sont obtenus.
COMPORTAMIENTO REOLÓGICO DE LAS VINAZAS DE UNA FÁBRICA MEXICANA DE BIOETANOL

Por

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PALABRAS CLAVE: Reología, Vinazas, Bioetanol, Viscoelástico, Energía de Activación.

Resumen
EL CONOCIMIENTO del comportamiento reológico de las vinazas es muy importante para la operación y diseño de un bioproceso de la caña de azúcar. Este estudio caracteriza comportamientos reológicos de residuos del proceso de bioetanol que emplean melazas como fuente de carbohidratos. Para esto empleamos un reómetro rotacional Antón Para MCR 301, sistema de cilindros concéntricos, platos Peltier para control de temperatura y software “Rheoplus” para la captura de datos. El efecto de la temperatura se compensó con un modelo de Arrenius, que mide la energía de activación de las vinazas en el rango 298-310 K. Los resultados muestran una energía de activación de 2,496x 10³ Cal/g-mol, un comportamiento no newtoniano, con características viscoelásticas i.e. en un rango bajo de efecto cortante (0-387L/s) como fluido ó flujo viscoso pseudo plástico). Después de esto, hay un punto de inflexión a altos efectos cortantes como sólido ó flujo elástico dilatante), porque las vinazas presentan una reestructuración material. Este comportamiento se debe a la compleja composición química de las vinazas de melazas, que son un subproducto del proceso azucarero. Para confirmar este comportamiento, se comparó con el comportamiento reológico de vinazas de jugos de caña como fuente de carbono, que mostró un comportamiento dilatante i.e. como un fluido fluido. Estos resultados muestran que, dependiendo de la composición química del sustrato (complejo/simple) se obtienen similares comportamientos reológicos (complejo/simple).
TECHNO-ECONOMICAL EVALUATION OF AN INTERACTIVE
DISTILLERY-SUGAR MILL TO GUIDE DECISION-MAKING
FOR THE BEST INCOME BALANCE

By

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KEYWORDS: Sugarcane, Ethanol, Cogeneration, Economics.

Abstract

The world ethanol production has grown rapidly from the beginning of this decade, driven by its greater use as a fuel. For example, in 2001, 42% of the world ethanol production was directed to beverage, cosmetics and the chemical industry whereas, in 2008, this figure went down to only 20%, with 80% being used as fuel (bioethanol). In fact, the bioethanol production grew from 18 000 million litres in 2001 to an estimate of 66 000 million litres in 2008. This means that ethanol is today the main alternative liquid fuel and ethanol obtained from sugarcane is the only source that does not compromise food sources, and it induces a significant reduction in the green-house effect. The technological option of the combined production of ethanol from sugarcane juices and very high pol (VHP) sugars, with an additional contribution of surplus bagasse for electric co-generation, has great appeal. This paper presents a techno-economical evaluation, with an interactive model that can guide the decision making process in the sugar mill/distillery complex, to get the best income balance according to the sugar and ethanol prices prevailing in the world markets. A Cuban case study is presented.

Introduction

The changes in cane sugar production and electric co-generation, in addition to producing ethanol, establish the criteria for a new operational scheme that is being introduced in many countries (MECAS, 2008, 2009).

With the purpose of increasing the efficiency of ethanol production, to get higher competitiveness and better sugar quality, and diminishing dependence on crude oil, the economical impact of a new operational scheme is analysed for Cuban conditions.

In the case of the alcohol distillery, the molasses fermentation stage was found to be one of the most inefficient parts of the process, and some studies were carried out before the implementation of the designed scheme to improve the production technology.

The studies that were carried out indicated the need to employ an adequate yeast strain and supplementation with inorganic salts, all to get a lower blackstrap molasses consumption and a higher exhaustion of the fermentation substrate.

In the conventional scheme, not using the juices from the filters in the sugar production, around 90% of the cane juices are devoted to sugar production and only 10% are directed to ethanol synthesis.

When the system of ‘Two Massecuites’ is used in the sugar production and separating the juices from the filters for alcohol production, 82% of the extracted juices from the cane are used to produce sugar and 18% for ethanol, increasing the surplus bagasse from 36% to 42%.
With this new scheme, the amount of sugar obtained is reduced, because the juices from the filters are not used for that task; and because the ‘Two Massecuites’ alternative limits the sugar recovery up to the B molasses. Both elements had contributed to the increase in the quality of the raw sugar produced.

With the conventional way, a standard or medium quality raw sugar is obtained, with no more than 96 Pol; with the new scheme, it’s possible to obtain a raw sugar with no less than 97 Pol, having wide market opportunities, higher prices, and increasing the net income.

**Materials and methods**

In this study, the increase in the net income obtained when the new scheme is applied is evaluated, having as a reference a Cuban Standard Mill, with a milling capacity of 2520 t of cane per day, with a constant alcohol production per day.

An incremental income is obtained by improvements in the efficiency of the distillery, as well as the increase in the quality of the sugar produced and the higher electric availability.

In the calculations of the income under both schemes, the prices prevailing in the Cuban national market are used (MARC, 2008).

The term ‘extraction’ is used to mean the technological step of using the extraction of the juices from the vacuum filters as substrate for the bioconversion to ethanol.

**Results and discussions**

The results obtained with the New Scheme are shown in Table 1.

<table>
<thead>
<tr>
<th>Table 1—Blackstrap molasses input indexes for alcohol production.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without extraction</td>
</tr>
<tr>
<td>400 kg/hL</td>
</tr>
</tbody>
</table>

Source: ICIDCA internal data.

It must be taken into account that the raw material used in the substrate for the ethanol production—with the new scheme—is B molasses, a product of higher purity than the C molasses that obviously contributes to the increase in the efficiency of the ethanol production, reducing the unit input.

The production values obtained with both schemes are shown in Table 2 and Table 3. The bases for the calculations are represented in Table 4.

| Table 2—Balance of production with the conventional scheme (three massecuites). |
|-----------------------------------|---|---|
| **Daily production balance**      | Units | Values |
| Milled cane                       | Tonnes | 2520 |
| Sugar                             | Tonnes | 314 |
| Blackstrap molasses               | Tonnes | 86.80 |
| Total ethanol production          | hL | 500 |
| With own molasses                 | hL | 217 |
| With molasses from other sources  | hL | 283 |
| Total Produced bagasse            | Tonnes | 195.30 |
| Surplus bagasse                   | Tonnes | 70.70 |
| % of surplus bagasse              | % | 36.20 |

**Note:** Alcohol Production only with C Molasses. Distillery Operation for 270 days per year: 100 in sugar season + 170 days off-season.

Source: ICIDCA Internal report
Table 3—Production balance with the new scheme.

<table>
<thead>
<tr>
<th>Daily production balance</th>
<th>Units</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milled cane</td>
<td>Tonnes</td>
<td>2520</td>
</tr>
<tr>
<td>Sugar</td>
<td>Tonnes</td>
<td>237</td>
</tr>
<tr>
<td>Blackstrap molasses</td>
<td>Tonnes</td>
<td>86.80</td>
</tr>
<tr>
<td>Total alcohol to be produced</td>
<td>hL</td>
<td>500</td>
</tr>
<tr>
<td>Alcohol during season from filter juices</td>
<td>hL</td>
<td>378</td>
</tr>
<tr>
<td>Alcohol during season from own molasses</td>
<td>hL</td>
<td>122</td>
</tr>
<tr>
<td>Alcohol during off-season with own molasses</td>
<td>hL</td>
<td>74.12</td>
</tr>
<tr>
<td>Alcohol at off-season from other source molasses</td>
<td>hL</td>
<td>425.88</td>
</tr>
<tr>
<td>Total bagasse</td>
<td>Tonnes</td>
<td>195.30</td>
</tr>
<tr>
<td>Surplus bagasse</td>
<td>Tonnes</td>
<td>82.24</td>
</tr>
<tr>
<td>% of surplus bagasse</td>
<td>%</td>
<td>42.11</td>
</tr>
<tr>
<td>Equivalent conventional fuel</td>
<td>Tonnes of Bunker C</td>
<td>16.45</td>
</tr>
</tbody>
</table>

Note: Two Massecuites. Alcohol production with B molasses + filters juices. Distillery operation for 270 days: In the sugar season 100 + 170 off-season. Source: ICIDCA Internal Report.

Table 4—Calculation bases for the production balance. (obtained from every tonne of milled cane)

<table>
<thead>
<tr>
<th></th>
<th>Traditional</th>
<th>New</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar (t)</td>
<td>0.12</td>
<td>0.09</td>
</tr>
<tr>
<td>Alcohol (hL)</td>
<td>0.09</td>
<td>0.20</td>
</tr>
<tr>
<td>Blackstrap molasses (t)</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>Bagasse (t)</td>
<td>0.08</td>
<td>0.08</td>
</tr>
<tr>
<td>Filters juices</td>
<td>0.18</td>
<td>0.18</td>
</tr>
<tr>
<td>For 100 L of alcohol are needed</td>
<td>400 kg of blackstrap molasses</td>
<td>One t of bunker C oil is equivalent to 5 t of whole bagasse</td>
</tr>
</tbody>
</table>

Source: ICIDCA Internal Reports

The surplus bagasse is increased by 1154 tonnes per day, which represents an increase of 6%, and gives opportunities for higher generation and sales of electricity, if this bagasse is used as fuel.

The electric balance is the figure obtained when the electricity consumption of the sugar-alcohol complex is deducted from the total electricity generated by the installation.

The electric balance of the sugar-alcohol complex during the season has two options: when the bagasse is burned as fuel or when not.

In the second case, the electric deficit drives an increase of the production costs as it is forced to buy electricity from the national grid; if burned, the complex is self-sufficient during the milling season, even having the possibility of selling electricity to the grid within the range of 2.51 to 2.98 MWh per day, for three or two massecuites respectively.

The alcohol remains constant in volume because there is no increase in the installed capacity. However, the need to transport molasses from other mills is dramatically reduced, because the ethanol plant can operate with its own molasses for a longer time, reducing the transportation costs of B molasses and giving a higher autonomy of production to the enterprise.

In Table 5, an increase in the total income of US$3m in the sugar-ethanol complex by the new scheme can be seen, when the bagasse is used as fuel to generate electricity.
Table 5—Total Income (USD) under both production schemes.

<table>
<thead>
<tr>
<th>Product</th>
<th>No extraction</th>
<th>With extraction</th>
<th>Increased income</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar</td>
<td>1 330 104</td>
<td>2 604 156</td>
<td>1 274 052</td>
</tr>
<tr>
<td>Total alcohol</td>
<td>2 493 200</td>
<td>3 291 650</td>
<td>798 450</td>
</tr>
<tr>
<td>Electricity</td>
<td>417 463</td>
<td>637 511</td>
<td>220 048</td>
</tr>
<tr>
<td>Total</td>
<td>6 733 967</td>
<td>9 824 967</td>
<td>3 091 002</td>
</tr>
</tbody>
</table>

Source: Own figures from ICIDCA’s internal reports.

Conclusions

The implementation of the proposed new scheme is in context with requirements and tendencies that are coming into force in world sugar industries. It allows an increase in the sugar quality, improving its commercialisation.

Additionally, a badly needed production flexibility is ensured in the sugar-ethanol combined manufacture, because the distillery can use juices and/or molasses and the whole range of their combinations, generating, at the same time, electricity, depending on the use of surplus bagasse as fuel.

It is a very promising way to give the cane sugar industry the opportunity to remain as an important economical component of sugar exporting countries.

REFERENCES


d’éthanol à partir de jus de canne, de sucre à pol très élevé (VHP) et la cogénération de l’électricité à partir de la bagasses de canne à sucre est très attrayante. Cette communication comporte une évaluation techno-économique, avec un modèle interactif qui peut guider la prise de décision dans le processus de rentabilité dans un ensemble industrielle usine de sucre-distillerie, pour obtenir un revenu optimal tenant compte les prix du sucre et de l’éthanol en cours sur les marchés mondiaux. Une étude de cas à Cuba est présentée.

EVALUACIÓN TÉCNICO-ECONÓMICA DE UN ESQUEMA INTERACTIVO DESTILERÍA-INGENIO AZUCARERO PARA GUIAR A LA TOMA DE DECISIONES PARA EL MEJOR BALANCE DE GANANCIAS

Por

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PALABRAS CLAVE: Caña de Azúcar, Etanol, Cogeneración, Economía.

Resumen

La producción mundial de etanol ha crecido rápidamente desde el inicio de la actual década, promovido por su mayor empleo como combustible. Por ejemplo, en el 2001 el 42% de la producción mundial de etanol se dirigía a las bebidas, cosméticos y la industria química, pero en el 2008 esta cifra descendió hasta solo el 20%, con el 80% empleado como combustible (bioetanol).

De hecho, la producción de bioetanol creció de 18 000 millones de litros en el 2001 hasta un estimado de 60 000 millones de litros en el 2008. Esto significa que el etanol es hoy el principal combustible líquido alternativo y que el etanol obtenido de la caña de azúcar es la única fuente que no compromete fuentes alimenticias e induce una reducción significativa del efecto invernadero. La opción tecnológica de una producción combinada de etanol de los jugos de caña y azúcares de muy alto Pol (VHP), con una contribución adicional de bagazo sobrante para cogeneración eléctrica tiene un gran atractivo. Este artículo presenta una evaluación técnico-económica, con un modelo interactivo que puede dirigir el proceso de toma de decisiones en el Complejo Ingenio-Destilería de alcohol, para alcanzar el mejor balance de ganancias, en correspondencia con los precios prevalecientes en los mercados para el azúcar y el etano. Se presenta un ‘Estudio de Caso’ para un Complejo cubano.
THE YEASTS, THEIR ECONOMIC, TECHNOLOGICAL AND DIVERSIFICATION POTENTIAL—PRESENT AND FUTURE

By

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KEYWORDS: Yeasts, Technologies, Nutrition, Flavour, Enhancers, Proteins, Pollution.

Abstract

A BRIEF look at the way yeasts and human beings met in ancient times, as well as an analysis of the primary and marginal yeasts such as baker’s yeast, fodder yeast from different agro-industrial residues, beer production, etc., with the possible alternatives for upgrading, are presented. The analysis of the yeasts propagation, as an established technology for the dramatic reduction of the polluting potential of distillery slops, with the simultaneous synthesis of a high quality fodder protein concentrate, as well as the evaluation of yeasts as a source of human nutrition complements, flavour enhancers, specific proteins and amino acids, organic pigments, plus the evaluation of the uses of the functional and thermal properties of yeasts, will complete the scope of this paper.

Introduction

Yeasts existed and influenced, from very early times. It is well known that there are no fossil yeasts. However, it is possible that they will be discovered soon (Poinnar et al., 1993).

Yeasts can be found in the most diverse environments, from the deserts (cactofic yeasts) to the Antarctic (criptococcus), as well as associated with insects, flowers, fruits, soils, plankton, etc.

Their unlimited ability to metabolise from hexose, pentose, and organic acids to hydrocarbons and their possibilities to synthesise from alcohols and fats to heterologous proteins gave the yeasts a distinguished active share in the ‘jump’ of life from the aqueous media toward superior forms.

About the history up to now

The yeasts and their ties with human beings are shown, from the very beginning, as faithful servants of the pleasure and the subsistence of our race (wine and bread).

The first to inform and systematise about it were the Egyptians who were in contact with yeasts but did not know their identity.

Sugarcane, in its long journey of 30 centuries from its origin in the Far East to the Caribbean was accompanied by the practice of fermenting its juices to obtain beverages of various characteristics and alcoholic content.

It was in America where the paradigmatic co-product of sugarcane was institutionalised: the Rum (Blanco, 1989).

In 1818, Erxleben established that the yeasts were living organisms, responsible for the fermentation. Finally, in 1857, Louis Pasteur demonstrated that their presence was essential for the fermentation process, giving the ‘final blow’ to the idea of the spontaneous generation. Hansen, in 1896, presented the first comprehensible taxonomic system for yeasts.
A landmark was when, at the end of the XVIII Century, fermentations were carried out to obtain solely yeasts. Between 1850 and 1870, an accelerated growth of baker’s yeast factories took place and, in 1867, A.L.G. Dehne invented and developed the well known ‘filter press’ for yeasts recovery, which is still in use.

The first producer of aerated yeasts was K.W. Howman, in England, in 1896. The first patent to backup the use of molasses as a substrate for yeasts production appeared in Austria in 1895, at the same time as the works of Delbrück started the use of the yeasts as a protein source in fodders, but also as a reliable option in human nutrition.

A solid development of aeration systems, with higher oxygen transfer rates and lower energy inputs, opened a new way for the genus *Saccharomyces*.

The food crisis during the World War I made it almost unavoidable to call on the *Torulopsis* and *Saccharomyces* as alternative sources of food for the population in Europe and also in the Caribbean. That stopped in 1918. Such experiences of massive production and use of SCP for human use favoured the come back in Germany in 1934–1936.

A new landmark in the evolution of biotechnology, that impacted on the massive production of yeasts, happened at the end of the World War II, with the required industrial production of penicillin. This forced the design and construction of big scale, highly aerated fermenters, for very pure cultures, which required efficient methods of agitation and aeration, accurate temperature measurement and control systems.

This was the milestone that marked the birth of the true biotechnology.

**Residual yeasts**

The *Saccharomyces* are used in an active form in the bakery industry, in the ethanol fermentation and other fermenting processes like the soya sauce (Luh, 1995).

Its inactive form, mainly in animal feeding and in human nutrition, is basically through its derivatives like the yeast extracts and autolises.

The high oil cost, plus the banning of oxygenating additives in gasoline, has driven an explosive expansion of ethanol production.

The residual slops of the distillation stage in the ethanol distillery is a highly contaminating stream. However, a technology has been developed that allows the aerobic fermentation of those slops, using a strain of *Candida* that metabolise the remaining organic matter to synthesise biomass. This depletes the BOD of the slops by 84% or more, and a highly valuable SCP dry concentrate of 45% protein content is obtained for fodder use.

**The yeasts as food**

The interest in the use of the yeasts as human and animal food corresponds basically to the following factors;

- The technological development reached about the baker’s yeasts that allows a deep knowledge of the biological mechanisms of their multiplication, as well as the necessary technological equipment for mass production. (Bergander, 1959)
- The availability of residual yeasts from other processes, mainly the production of ethanol.
- Abundant sources of raw materials of low cost, like the molasses from the production of cane sugar, vinasse from alcohol manufacture, starch, sulfite liquor, n-alkenes (Otero, 1989).
- The low availability or high prices of food, due to droughts, fuel shortages, etc.

Today, the protection of the environment has been added to the problems mentioned before. Yeasts production became a proved way to reduce the environmental contamination by some industries such as the ethanol industry.
The value of the yeasts as food

Foods must cover a series of requisites that make them acceptable. The FAO Organisation has established the pre and clinical tests that any food must undergo to be recognised as Gras (Generally Recognised as Safe).

**Digestion and absorption**

To be able to use the nutritive components of a food, they must be available at the digestion and during the absorption. Any additive like yeasts are forced to show, not only to be safe and nutritive, but also to have physical and chemical-physical properties that facilitate their use and ensure an attractive aspect of the final product. Among them are humidity, particle size, bulk density, palatability, and oxidation.

The yeasts are not only an ideal, safe, plastic source of high quality proteins, but also of badly required vitamins, oligoelements and essential amino acids

**The yeasts as a complement of human foods**

The yeasts as a complement in the human diet satisfy the concept of ‘functional food’, being able to produce beneficial metabolic and physiological effects, like the reduction of glycaemia, prevention of prostate cancer, etc.

In addition to the basic nutritional functions, the yeast cells could be considered as nutraceutics, as is the case of the different chromium and selenium complexes, etc. (Roberfroid, 1999).

The dry *Saccharomyces* cells are used as an optimum source of dietetic fibre and vitamins of the B complex. They also have eight essential amino acids required for healthy adults and arginine and histidine basic for children. Additionally, they supply essential minerals, especially chromium and selenium (Dziezak, 1987; Peixoto, 1996).

The essential amino acid composition of the yeasts has no difference in comparison with the FAO/WHO standard, except for the chemical score of the yeasts autolisate that reached 84% in relation to the sulfurous amino acids.

**The state of the art and some recent tendencies**

The last years of the 20th century and the beginning of the 21st show really interesting tendencies of special significance in the relation of yeasts with mankind.

Yeasts show even more abilities that, wisely used, have an indisputable space in health, nutrition and industrial production (Leimer and Finguerut, 2005).

An example is the possibility of accumulating significant amounts of minerals present in the culture media. It is the case of organic selenium used successfully because it resembles the way this mineral is present in nature.

A similar situation happens with chromium, a very active constituent of the glucose tolerance factor (GTF) that becomes a necessary cofactor to enhance the activity of insulin to transport the glucose from the circulatory tissues to the peripheral ones.

The strengthening of the immune system in animals is a new science and here also the yeasts are getting a special share.

Hydrogen, as an option to establish an ecologically friendly energetic alternative, is a place where yeasts will play a decisive role.

The impact of the yeasts in the solution of the basic problems that mankind is facing today: food, energy and the protection of the environment, is clear and evident; Yeasts will be surprising us every day.
REFERENCES


LES LEVURES: POTENTIEL ÉCONOMIQUE, TECHNOLOGIQUE ET DE DIVERSIFICATION - PRÉSENT ET AVENIR

Par

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MOTS-CLÉS: Levures, Technologies, Alimentation, Arôme, Promoteurs, Protéines, Pollution.

Résumé

CETTE COMMUNICATION comporte un bref coup de œil sur la façon dont les levures et les êtres humains se sont rencontrés dans l'Antiquité, ainsi qu’une analyse des levures principales et marginales telles que la levure boulangère, fourragère et celle émanant de résidus agro-industriel et de la production de bière, etc., qui sont susceptibles d’être améliorées. L’analyse de la propagation de levures, comme une technologie établie pour la réduction considérable du potentiel polluant de la vinasse de distillerie, avec la synthèse simultanée d'un concentré de protéine de haute qualité fourragère, ainsi que l'évaluation des levures comme une source complémentaire d’alimentation humaine, d’amélioration de saveur, de production de protéines et d’acides aminés spécifiques, des pigments organiques et l'évaluation de l'utilisation des propriétés fonctionnelles et thermiques des levures, compléteront le contenu de ce document.
LAS LEVADURAS. SU POTENCIAL ECONÓMICO, TECNOLÓGICO Y DIVERSIFICADOR. PRESENTE Y FUTURO

Por

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PALABRAS CLAVE: Levaduras, Tecnologías de Nutrición, Acentuadores de Sabor, Proteína, Contaminación.

Resumen

SE PRESENTA una breve visión del modo en que las levaduras y los seres humanos se encontraron en la antigüedad, así como un análisis de cómo las levaduras marginales y primarias, como las de panificación, forrajeras obtenidas de diferentes residuos agroindustriales, de la producción de cerveza, etc. pueden ser revalorizadas. La visión total de este trabajo se completa con el estudio de la propagación de las levaduras, como una tecnología establecida, para una dramática reducción del potencial contaminante de los residuos de las destilerías, con la síntesis simultánea de un concentrado proteico de alta calidad, así como la evaluación de las levaduras como fuente de complemento para la alimentación humana, potenciadores de sabor, proteínas específicas y aminoácidos, pigmentos orgánicos, a más de la consideración de los usos de las propiedades funcionales y térmicas de las levaduras.
DEMONSTRATION OF CELLULOSIC ETHANOL PRODUCTION FROM SUGARCANE BAGASSE IN AUSTRALIA: THE MACKAY RENEWABLE BIOCOMMODITIES PILOT PLANT

By


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KEYWORDS: Lignocellulose, Bioethanol, Biorefinery, Biocommodities, Pilot Plant.

Abstract

The ready availability of sugarcane bagasse at an existing industrial facility and the potential availability of extra fibre through trash collection make sugarcane fibre the best candidate for early stage commercialisation of cellulosic ethanol technologies. The commercialisation of cellulosic ethanol technologies in the sugar industry requires both development of novel technologies and the assessment of these technologies at a pre-commercial scale. In 2007, the Queensland University of Technology (QUT) received funding from the Australian and Queensland Governments to construct a pilot research and development facility for the production of bioethanol and other renewable biocommodities from biomass including sugarcane bagasse. This facility has been built on the site of the Racecourse Sugar Mill in Mackay, Queensland and is known as the Mackay Renewable Biocommodities Pilot Plant (MRBPP). This research facility is capable of processing cellulosic biomass by a variety of pretreatment technologies and includes equipment for enzymatic saccharification, fermentation and distillation to produce ethanol. Lignin and fermentation co-products can also be produced in the pilot facility.

Introduction

As a result of the increasing scarcity of crude oil, rising oil prices and concerns about the geopolitical concentration of remaining oil reserves, many countries are now seeking alternative energy sources for transport fuels. The need for transport fuels that are renewable and sustainable and have low greenhouse gas emissions is also underpinning the development of new fuel production technologies.

Second generation biofuels utilise non-food feedstocks for bioethanol production. Materials considered for second generation biofuel production are generally lower value feedstocks, including crops grown on marginal agricultural land or underutilised biomass residues of existing agricultural crops such as sugarcane bagasse.

Sugarcane bagasse is a complex mixture of cellulose, hemicellulose and lignin with minor amounts of ash, proteins, lipids and extractives. The cellulose and hemicellulose components of sugarcane bagasse can be pretreated, hydrolysed and fermented with varying efficiencies into ethanol (IEA, 2004; Olsson et al., 2005).

Pilot plants are an essential tool for the development of new technologies, bridging the gap between laboratory research and commercial application. Pilot plants are used to optimise key process parameters such as yield, rate and efficiency at a scale much larger than that used for laboratory development and in equipment that mimics large scale industrial facilities.

These plants allow key process economics to be evaluated and provide information on both the robustness of the process and scale-up data for the design of the commercial facility.
Pilot plants also provide the opportunity to produce a significant amount of product for pre-commercial testing.

In Australia, the Queensland University of Technology (QUT) has constructed a pilot research and development biorefinery for the production of biofuels and other renewable biocommodities from biomass including sugarcane bagasse.

In a biorefinery, bagasse is typically fractionated into its major component streams and value is added to each component through the production of multiple co-products, such as bioethanol, compounds derived from lignin, specialty sugars, organic acids, fermentation products and energy products including biodiesel, hydrogen and methane (Figure 1).

![Figure 1—A typical concept drawing for a sugarcane biorefinery.](image)

The Mackay Renewable Biocommodities Pilot Plant

The Mackay Renewable Biocommodities Pilot Plant (MRBPP) has been funded jointly by the Queensland Government, the Australian Government and QUT. Queensland Government funding was provided through the Innovation Building Fund which was established to promote the development of research infrastructure for science and technology in Queensland. Under the Australian Government National Collaborative Research Infrastructure Strategy funding conditions, facilities are made available by the host organisations for both public and private sector research. The priority and cost of access is determined in accordance with an Access and Pricing Code, and access for meritorious, eligible research is provided at a subsidised rate to enhance facility usage.

The MRBPP has been built at the Mackay Sugar Limited (MSL) Racecourse Mill in Mackay, Queensland. Mackay is a major sugarcane producing region in Australia, with this region producing around 10 million tonnes of sugarcane per annum. Co-location on the site of a sugar factory allows the facility ready access to feedstocks for the process (bagasse, juice and molasses) and enables the utilisation of essential services from the Racecourse Mill site.

Key elements of the facility include site infrastructure consisting of the main factory building, office and laboratory facilities, plant and equipment and facility labour. Plant and equipment includes bagasse handling, pretreatment, saccharification, fermentation and ethanol purification and concentration. Laboratory process development units are available including a
Mettler Toledo RCe1 reaction calorimeter with on-line infra-red detection. This unit enables the development of comprehensive chemical reaction kinetic information.

Plant and equipment for the MRBPP facility has been selected to be capable of demonstrating a range of biorefinery processes (such as that shown in Figure 2). The major pretreatment reactor has been designed and manufactured by Andritz Inc and is a Hastelloy two-stage batch reactor capable of processing a range of biomass feedstocks, and demonstrating several pretreatment processes. These processes include pretreatment using both alkaline and dilute acid processes at temperatures up to 230°C and pressures to 26 bar. Further, the equipment will enable the fibrous material to be ‘exploded’ out of the reactor in the rapid depressurisation process known as steam explosion. Providing the flexibility to simulate a range of pretreatment processes maximises the value of the facility both to the research community and to potential industry partners.

Glucose and pentose fermentation to ethanol will be undertaken in a range of fermenters of varying scales up to 10 000 L. The MRBPP facility has been designed with an enclosed fermentation facility, capable of being certified to physical containment level 2 (PC2).

This containment level will enable the facility to trial a range of fermentation organisms, including recombinant organisms that have been modified for enhanced pentose fermentation capability. Ethanol produced in the pilot plant will be concentrated using a distillation column to produce a hydrous ethanol product.

One of the key co-products from the biorefinery is lignin – an aromatic polymer with many valuable properties. Research work at QUT and through the Cooperative Research Centre for Sugar Industry Innovation through Biotechnology (CRC-SIIB) has investigated a range of potential uses for lignin including as a phenol substitute in phenol-formaldehyde resins, as a water-borne barrier coating and as a component of lignin-PF films and biocomposite materials (Doherty et al., 2007).

The pilot plant includes equipment for both the delignification of biomass and the subsequent recovery and purification of lignin. The purified lignin is able to be produced in significant quantities to enable further product development and testing.

**Conclusion**

The MRBPP is valuable research and development infrastructure for both the international sugarcane research community and future biomass-based industries. This facility provides unique infrastructure for biomass utilisation research, particularly focussed upon the enzymatic conversion of cellulose into ethanol in an integrated biorefinery.
Additionally, the ability to produce novel co-products such as lignin allows opportunities for large scale product development and testing.

The MRBPP has sufficient flexibility to undertake trials on fermentation technologies based on sugar, molasses and bioethanol process streams to manufacture organic acids and other products. Further chemical derivatisation and transformations are also possible dependent upon process conditions.

Acknowledgements

The authors wish to thank the Australian Government Department of Innovation, Industry, Science and Research and the Queensland Government Department of Tourism, Regional Development and Industry, QUT and Mackay Sugar Limited for the on-going funding and support for the establishment of the MRBPP.

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DEMOSTRACIÓN DE LA PRODUCCIÓN DE ETANOL CELULOLÍTICO DEL BAGAZO DE LA CAÑA DE AZÚCAR EN AUSTRALIA: LA PLANTA PILOTO DE PRODUCTOS RENOVABLES DE MACKAY

Por

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PALABRAS CLAVE: Lignocelulosa, Bioetanol, Biorefinería, Bioproductos, Planta Piloto.

Resumen

La segura disponibilidad de bagazo de la caña en facilidades industriales existentes y la potencial disponibilidad de fibra extra por la vía de la recolección de los residuos agrícolas hacen de la fibra de la caña de azúcar la mejor candidata para una temprana comercialización de tecnologías de etanol celulósico. La comercialización de tecnologías de etanol celulósico en la industria azucarera requieren tanto el desarrollo de tecnologías novedosas, como el desarrollo de estas tecnologías a una escala pre-comercial. En el 2007 la Universidad Tecnológica de Queensland (QTU) recibió financiamiento de los Gobiernos de Australia y de Queensland, para la construcción de una instalación piloto de investigación y desarrollo para la producción de bioetanol y otros bioproductos renovables a partir de biomasa incluyendo bagazo de la caña de azúcar. Esta instalación se construyó en áreas del Reecourt Sugar Mill en Mackay, Queensland y es conocida como la Planta Piloto de Bioproductos Renovables de Mackay (MRBPP, en inglés). Esta facilidad investigativa es capaz de procesar biomasa celulósica mediante una variedad de tecnologías de pretatamiento e incluye equipos para sacarificación enzimática, fermentación y destilación, para producir etanol. Se pueden producir igualmente lignina y coproducios de la fermentación en esas facilidades piloto en Mackay.
SAN CARLOS ‘SUGAR CANE TO BIO-ENERGY—A SUCCESS STORY’

By

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KEYWORDS: Bio-energy, Fuel Ethanol, Cogeneration, Biomass, Zero Discharge.

Abstract

THE FIRST commercial scale sugarcane to bio-energy (i.e. fuel ethanol and grid connected cogeneration) plant in Philippines commenced successful operation in January 2009. The integrated facility was set up by San Carlos Bio-energy Inc. (a joint venture of Bronzeoak Clean Energy Inc, United Kingdom) near San Carlos on Negros Occidental Island, Philippines. The technologies have been provided by Indian companies, ISGEC John Thompson (IJT) for the complete plant and KBK Chem-Engineering for ethanol. The facility comprises a raw syrup plant using state of the art energy efficient juice extraction, clarification and evaporation plant followed by fermentation, distillation and dehydration for production of fuel ethanol. After concentration of the vinasse, 75% is used for dilution of syrup and the balance 25%, along with the filter-cake, is used for bio-composting for organic fertiliser which results in zero effluent discharge. The Co-generation plant comprises an 8 MW extraction-cum-condensing turbo generating set and a 45 TPH, 67 kg/cm² (g) travelling grate single pass water tube IJT make boiler suitable for firing a wide variety of biomass, mainly bagasse, woodchips, eco-friendly cane trash and bio gas to facilitate year round cogeneration. The total process steam consumption for production of fuel ethanol is 350 kg/tonne of cane. The plant has achieved 110% capacity utilisation with all the efficiency parameters in the second month of the trial season. The plant is meeting World Bank standards of stack emissions through an electrostatic precipitator and zero effluent discharge through bio-composting of the vinasse. The plant is fully automated through a DCS-based control system with facility for remote operations. The surplus power export to grid is 60 kWh/tonne cane. This opens up a new avenue in the South East Asian region for profitable production of green energy.

Introduction

These days with increasing demand for fuel, ethanol blended with gasoline is the most widely used alternative fuel.

Replacing some petroleum use with renewable biomass resources and electricity is appealing but the approach brings with it important questions:

1. What is the best use of limited biomass resources?
2. How to replace litres of gasoline in a timely fashion, maximising the greenhouse gas emission reductions and accounting for energy security issues?
3. Can we achieve these goals without reaching technology limits?
Here is the answer and following benefits of converting sugarcane to bio-energy:

- Insulation from fluctuation of fossil fuel prices in the world market.
- Utilisation of alternative, clean and renewable fuels for energy without compromising food security.
- Promotion of countryside development and rural employment.
- Mitigation of toxic and greenhouse gas (GHG) emissions.

In view of examining ways to abate gasoline consumption by adopting alternative fuels and shifting of energy to the electricity grid, IS GEC John Thompson, INDIA, an EPC group has emerged with integrated sugarcane to ethanol plant including cogeneration of power.

Building on prior experience in the field of sugar machinery and ethanol, ISGEC John Thompson along with KBK were involved to design, develop, construct, erect and commission an integrated sugarcane to ethanol complex including power cogeneration at San Carlos Bioenergy Inc. in the Philippines near San Carlos on Negros Island (Figure 1.)

The plant is designed to produce 125 000 litres/day of anhydrous ethanol directly from cane juice with 8 MW power generation and it emits 50 tonnes per day carbon dioxide.

An anaerobic digestion plant with integrated waste treatment plant is installed to minimise the liquid and solid discharge from the plant.

The complete concept of design engineering, erection and commissioning of the plant is described in this paper.

Fig. 1—San Carlos Bio-energy Inc., Philippines ‘Powering the Future’.

**Concept of plant design**

**Energy security**

The plant is fueled entirely by indigenous biomass resources, particularly bagasse and eco-friendly cane trash and wood chips.

The ethanol plant is designed to produce 125 000 litres of anhydrous fuel grade ethanol per day and 30 million litres annually. 8 MW of energy will be produced through cogeneration, with approximately 4 MW available for export.

**Environment**

The ethanol plant conforms to World Bank emission standards. No NOx and SOx will be emitted. All liquid discharge is reused for the plant’s cooling systems and irrigation. Solids on the other hand are recycled as organic fertiliser.

Biogas produced and captured per day is utilised as additional fuel to the boiler.
Agro economy

Farmers cultivating biofuel feedstock, cane, will have a ready and viable market and will progressively increase their income. This facility provides numerous farm services and plant site employment opportunities. Stable energy supply in the area will encourage further agro-industrial development, resulting in improved socio-economic status of the local communities.

Main components of the plant

To meet local and international environmental and technical standards, the following are the main components of the plant:

- Cane handling and milling.
- Juice clarification and evaporation.
- Fuel ethanol Plant.
- Cogeneration plant.
- Carbon dioxide recovery plant.
- Anaerobic digestion plant.
- Bio-composting.

Flow processes

The flow processes and functions of the integrated bio-ethanol plant are described below.

Cane crushed through mills driven by energy efficient shaft mounted hydraulic drives (Figure 2).

The juice is clarified through a defecation process.

Juice Evaporation to 40° Bx in a state of the art fully-automated multi-effect evaporator station with all waste heat recovery system, condensate flash recovery for minimum steam consumption which is only 180 – 200 kg/tonne cane for raw syrup production to facilitate more power export (Figure 3).
Ethanol production from raw syrup.

The ethanol plant comprises three distinct stages: fermentation, distillation and dehydration. Syrup received from the raw syrup plant is diluted and fed to the fermentor for continuous fermentation (Figure 4).

In addition to production of relatively low alcohol feed to the distilling stage, fermentation results in the generation of carbon dioxide. This is a potential saleable byproduct for use in food and beverage industries. A CO₂ capture plant is installed.

The distillation plant is designed to operate under vacuum and use low-pressure steam from the cogeneration plant. Preheated fermented wash is fed at the top of the distillation columns. As the wash descends, vapours containing alcohol are separated.
Up to and about 75% of the spent wash is re-circulated to the fermentation plant in order to dilute the incoming cane syrup with the balance directed to the effluent treatment plant. This approach reduces both raw water make-up requirements and the resulting less effluent produced. However, it does increase effluent COD/BOD (chemical oxygen demand / biological oxygen demand).

Leaving the distillation stage, the separated alcohol vapours are sent to the dehydration stage where desiccant beds are used to remove residual water. The plant will have two 100% beds with one bed operating while the other is regenerated by steam from the cogeneration plant. Dehydration will result in ethanol with a concentration of 99.85%. Before leaving the plant, ethanol will be denatured.

It’s the responsibility of ethanol purchasers to blend the ethanol with gasoline to E5 or E10 grade before commercial sale at gasoline stations for common use in the Philippines.

The ethanol plant typically results in a high COD and BOD effluent. In view of modern practice, the first stage in treatment of effluent at S CBI is by anaerobic digestion. This substantially reduces COD/BOD with production of biogas, which is used as a supplementary fuel for the boiler.

Following anaerobic treatment, the effluent is directed to a membrane filtering system for separation into a permeate stream (low COD/BOD) and a concentrated stream (high COD/BOD) stream.

The SCBI design incorporates recycling of the permeate (relatively clean) stream within the facility. The main part of the concentrate stream will be used to aid bio-composting of the residual filter cake from the raw syrup plant to which boiler ash and anaerobic digestion solids are added. The resulting bio-compost will be returned to the fields for soil nourishment as organic fertiliser. In addition, any surplus liquid concentrate that is not used for composting will also be disposed by spraying onto cane fields.

Cogeneration

The cogeneration boiler is sized at 45 tonne/h and produces steam at 67 kg/cm² (g) and 480 ± 5°C. This steam drives an extracting-cum-condensing steam turbine to produce electricity, for in house consumption and facility for exporting surplus power (Figure 5). From an energy perspective, the plant is designed to be self-sufficient using bagasse from the mill and biogas from the anaerobic digestion plant. For longer operation wood chips can also be used.

Fig. 5—Cogeneration plant.
Depending on the availability of sugarcane, SCBI's operations will fall into two distinct modes: a) the on-season mode, the period when sugarcane is harvested and available for processing, b) the off-season mode, the period when no sugarcane is available. During on-season mode, the cane mill, raw syrup plant, ethanol plant and cogeneration plant with all associated services will be in operation. During the off-season mode, plant operations are limited to that of the cogeneration plant and associated services.

Over the course of a year, the plant will process over 450,000 tonnes of cane while producing 39 million litres/year of ethanol. The cogeneration plant will generate 7.5/8 MW during the on-season mode, allowing about 3.5/4 MW for export to grid. During the off-season, the cogeneration plant is predicted to increase export to 4 MW due to lower on-site consumption. Plant operation parameters are as follows:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual cane throughput (tonnes)</td>
<td>450,000</td>
</tr>
<tr>
<td>Daily ethanol production (liters)</td>
<td>125,000</td>
</tr>
<tr>
<td>Ethanol purity (% v/v) min</td>
<td>99.85%</td>
</tr>
<tr>
<td>Annual ethanol production (liters)</td>
<td>39 million</td>
</tr>
<tr>
<td>On season power generation (MW)</td>
<td>7.5/8</td>
</tr>
<tr>
<td>Off season power generation (MW)</td>
<td>5/5.5</td>
</tr>
</tbody>
</table>

Contract risks have been mitigated by the appointment of international consulting engineers, to manage the procurement and construction process during post-financial close project execution.

This company is registered as a CDM (Clean Development Mechanism) project and will earn additional revenue from the sale of CERs (carbon credits). These should accrue from four sources, a) displaced fossil generated electricity, b) displaced vehicle use of gasoline, c) methane captured by anaerobic digestion process, d) carbon dioxide captured and sold for commercial use. At the time of writing, the CDM process has received approval for source (a). The other sources are the subject of ongoing discussions and decisions by the UNFCCC (United Nations Framework Convention on Climate Change) methodology panel.

Since the cogeneration plant uses only biomass, only very low sulfur dioxide emissions will occur. The main control is for particulates using electrostatic precipitators. The design of the ethanol plant effluent treatment was both a technical and commercial challenge in terms of achieving the low standard for the final effluent quality and in terms of finding a cost optimised approach. The final solution results in zero effluent discharge to surface water by a combination of recycling, bio-composting and limited use of liquid effluent as a soil nutrient.
L’UNITÉ DE SAN CARLOS AU PHILIPPINES ‘DE LA CANNE À SUCRE À LA BIO-ÉNERGIE: UNE RÉUSSITE’

Par

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Résumé

LE PREMIER complex industriel commercial à succès de la canne à sucre à la bio-énergie (c'est-à-dire bioéthanol et cogénération de l’électricité à la grille nationale), au Philippines a été mis en opération en janvier 2009. Cet ensemble industriel intégré a été institué par la San Carlos Bio-energy Inc. (une subsidiaire de Bronzeoak Clean Energy Inc, Royaume-Uni) près de San Carlos sur l’île de Negros Occidental, aux Philippines. Les technologies ont été fournies par les sociétés indiennes ISGEC John Thompson (IJT) pour l’ensemble industriel et KBK Chem-Engineering pour l’éthanol. L’installation comprend une unité pour produire du sirop à l’état brut à l’aide des technologies les plus avancées en matière d’efficacité d’énergie pour l’extraction, la clarification et l’évaporation suivie de la fermentation, de la distillation et la déshydratation pour la production de bioéthanol. Après la concentration des effluents, 75% est utilisé pour la dilution de sirop et la balance de 25% en mélange avec les écumes, est utilisé pour produire des engrais organiques par bio-compostage, ce qui se traduit par une absence complète de production d’effluents. L’unité de co-génération com prend un turbo alternateur extraction-cum-condensation de 8 M W et une chaudière à grille simple IJT de 45 TPH, 67 kg/cm² (g) pouvant être utilisée pour une grande variété de types de biomasse, principalement la bagasse de canne à sucre, des copeaux de bois, la paille de canne écologique et du biogaz qui permettent la cogénération pendant toute l’année. La consommation totale de vapeur pour la production de bioéthanol est de 350 kg/tonne de canne à sucre. L’ensemble industriel a atteint 110% de sa capacité tenant compte de tous les paramètres d’efficacité, au cours du deuxième mois de la saison d’essai. Le complexe industriel satisfait les normes de la Banque Mondiale pour les émissions à travers l’utilisation d’un filtre électrostatique et l’élimination totale des effluents par bio-compostage. L’ensemble industriel est entièrement automatisé par le biais d’un système de contrôle digitalisé (DCS) avec facilité pour des opérations de contrôle à distance. L’exportation du surplus de électricité à la grille est de 60 kWh par tonne de canne. Cela ouvre une nouvelle avenue pour une production d’énergie verte rentable dans le Sud-est Asiatique.
SAN CARLOS ‘CAÑA DE AZÚCAR A LA HISTORIA DE ÉXITO DE LA BIOENERGÍA’

Por

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PALABRAS CLAVE: Bioenergía, Etanol Combustible, Cogeneración, Biomasa, Cero Descargas.

Resumen
LA PRIMERA planta a escala industrial en Filipinas para bioenergía (i.e. etanol combustible y cogeneración conectada a la red pública) comenzó su exitosa operación en Enero del 2009. La instalación integrada fue establecida por San Carlos Bio-energy Inc. (una inversión conjunta de Bronzeoak Clean Energy Inc., United Kingdom) cerca de San Carlos en la Isla Negros Occidentales, Filipinas. La tecnología fue suministrada por compañías indias, ISGEC John Thompson (IJT) para la planta completa y KBK Chem-Engineering para etanol. La instalación comprende una planta de sirope azucarero crudo empleando tecnología de “Estado del Arte” en cuanto eficiencia energética para la extracción del jugo, clarificación y evaporación, seguida de fermentación, destilación y deshidratación para la producción de etanol combustible. Posterior a la concentración del vinasse, 75% se emplea para la dilución del sirope y el balance del 25%, junto con los filtros, se utiliza para el biocomposteado para fertilizante orgánico, lo que resulta en una emisión cero de efluentes. La planta de cogeneración comprende un generador de extracción-condensación de 8 MW de capacidad y 45 TPH, 67 kg/cm² (g), parrilla móvil, tubos de agua IJT de un paso, hacen que la caldera sea capaz de combustionar una amplitud variedad de biomasa, principalmente bagazo, astillas de madera, residuos cañeros ecoamigable y biogas, todo para facilitar la cogeneración todo el año. El consumo total de vapor para la producción de etanol combustible es de 350 kg/t de caña. La planta ha alcanzado una utilización de 110% de su capacidad, con todos los parámetros de eficiencia en su segundo mes de la campaña azucarera de prueba. La planta también satisface los estándares de emisión de I Banco Mundial mediante un precipitador electrostático y cero descarga de efluentes por la biocompostación de las vinazas. La planta está to talmente automática mediante un sistema de control DCS con facilidades para la operación remota. La energía excedente exportada a la red pública, es 60 kWh/t de caña. Esto abre una nueva avenida en la región del sureste de Asia para la producción rentable de energía verde.
DESIGN, MANUFACTURING AND MAINTENANCE OF SUGAR MILL EQUIPMENT: ISSCT ENGINEERING WORKSHOP 2008 SUMMARY REPORT

By

G.A. KENT
ISSCT Engineering Section Chairman

KEYWORDS: Sugar, Mill, Sugar Mill Equipment, Design, Manufacture, Maintenance.

Abstract

The ISSCT Engineering Workshop 2008 in Brazil was well attended with 62 participants including 39 overseas visitors from 15 countries. The workshop addressed the theme Design, manufacturing and maintenance of sugar mill equipment. From the technical sessions, the following conclusions were drawn: several speakers articulated a shared vision of the future of the Brazilian sugar industry. This shared vision gives considerable confidence that the vision can become a reality; there is an increased focus on energy products. As a result, the reduction of factory energy consumption in order to maximise the energy available for products is also a focus; new equipment and products are being developed with reduced power consumption, lower capital and maintenance costs, and better performance. Methods presented for reducing maintenance costs included the use of a maintenance management system, condition monitoring and material selection. The workshop was held in conjunction with Piracicaba’s annual SIMTEC exhibition for the sugar and alcohol industries that provides a forum for technical presentations and discussion, and showcases products and services from manufacturers and service providers. In return for holding the workshop in conjunction with SIMTEC, SIMTEC provided sponsorship for the workshop, including paying travel and accommodation costs for two invited speakers, and organisation for the workshop. The ISSCT and SIMTEC technical programs were arranged so that their technical sessions did not clash, and the ISSCT program was extended a day to provide an opportunity for ISSCT participants to attend the SIMTEC exhibition. Informal feedback from workshop participants suggested that the arrangement between ISSCT and SIMTEC worked well. Site visits to two manufacturing facilities and two sugar mills were arranged as part of the workshop.

Introduction

An ISSCT Engineering Workshop was held in Piracicaba, Brazil from 30 June to 4 July 2008. The theme of the workshop was Design, manufacturing and maintenance of sugar mill equipment.

The workshop was held in conjunction with SIMTEC (Symposium and Technology Exhibition on the Sugar & Alcohol Industry). SIMTEC is an annual event held in Piracicaba that provides a forum for technical presentations and discussion, and showcases products and services from manufacturers and service providers. SIMTEC provided sponsorship for the ISSCT workshop and handled most of the workshop organisation.

To better integrate with SIMTEC, the ISSCT workshop was extended from its usual four days to five days. Technical sessions were held throughout the first day and on the mornings of the second and third days. SIMTEC started on the second day of the workshop and continued until the final day. SIMTEC was held in the afternoons and evenings of the second and third days so it did not clash with the workshop technical sessions. The afternoon programs for the second and third
days of the workshop were kept free for SIMTEC attendance so that ISSCT participants could attend the SIMTEC technical sessions and trade exhibition. Site visits were held on the fourth and fifth days of the workshop.

The workshop was attended by a total of 62 participants, including 39 overseas visitors from 15 countries.

Attendance included the ISSCT Factory Commissioner, Juliusz Lewinski, the author (Geoff Kent, ISSCT Engineering Section Chairman), and five members of the ISSCT Engineering Section Committee—Paulo Delfini, D.K. Goel, Adolfo Gomez, Dave Meadows and Boris Morgenroth.

Paulo Delfini from Brazil acted as Chairman of the Workshop Organising Committee in the lead up to the workshop while the other four members of the committee in attendance chaired the four main technical sessions.

Sponsorship

Financial support for the workshop was provided by SIMTEC, Dedini, TGM and WBA. In addition to the support provided in organising the workshop, SIMTEC paid the travel and accommodation costs for two invited speakers: Mr Alan Yarrow of Australia and Mr Manuel Enríquez of Mexico. TGM and Dedini provided lunch for the delegates during the two days of site visits.

Zuckerindustrie and International Sugar Journal provided a free one-page advertisement in their respective journals in advance of the workshop.

Opening session

The opening session of the workshop, chaired by the author, included presentations from the following invited speakers:

A welcome from Paulo Delfini, the Chairman of the Workshop Organising Committee.

The official opening of the workshop by José Francisco Calil, the Secretary of Economic Development for the City of Piracicaba.

An overview of the sugar industry in Brazil by Edgard Gomes Beauclair of STAB.

A welcome to SIMTEC from Alvaro Vargas, Directory of Industry Centre of Sao Paulo State (CIESP).

Edgard Beauclair’s presentation provided a good overview of the sugar industry in Brazil and its vision for the future. He stressed that the industry has been unfairly subjected to international criticism due to two misconceptions:

The production of ethanol from sugarcane is not replacing food production. Most new cane land was previously unproductive.

New cane land is not within the Amazon region of Brazil.

The Brazilian industry is focussed on the use of sugarcane as an energy crop. Products include ethanol from juice products, electricity, biodiesel and ethanol from sugarcane biomass.

Technical sessions

Introductory remarks

The conference included four technical sessions. The session topics and their respective chairmen are listed in Table 1.

Each session contained a keynote address that was intended to lead into a discussion of that topic. The keynote speakers are also listed in Table 1. Additional technical presentations were also given.
Table 1—Session topics and chairmen.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Chairman</th>
<th>Keynote speaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factory and factory system design and maintenance</td>
<td>Dave Meadows, Tongaat Hulett, South Africa</td>
<td>José Luiz Olivério, Dedini, Brazil</td>
</tr>
<tr>
<td>Factory equipment design and manufacture</td>
<td>Boris Morgenroth, IPRO, Germany</td>
<td>Boris Morgenroth, IPRO, Germany</td>
</tr>
<tr>
<td>Factory equipment maintenance</td>
<td>D.K. Goel, ISGEC John Thompson, India</td>
<td>Alan Yarrow, ISS-Machine Health, Australia</td>
</tr>
<tr>
<td>Novel and unconventional equipment designs</td>
<td>Adolfo Gomez, Cenicaña, Colombia</td>
<td>Dave Meadows, Tongaat Hulett, South Africa</td>
</tr>
</tbody>
</table>

**Factory and factory system design and maintenance**

*Keynote address: Factory and factory system design (José Luiz Olivério)*

José Olivério outlined Dedini’s view for the evolution of the sugar industry in Brazil, focusing on sustainable development by producing biofuels and bioenergy from sugarcane. He described traditional factory configurations, current trends and a future vision.

The traditional factory configuration in Brazil produces sugar, bioethanol and bioelectricity. To maximise energy output, there is a need to minimise factory energy consumption. A traditional factory can maximise energy output by replacing turbine drives with electric or electro-hydraulic drives, generating high pressure (100 bar) steam, producing low, low pressure steam, improving process control and biogasification of dunder.

Considered as an energy source, 1 tonne (dry basis) of cane in the field (made up of one-third sugar, one-third bagasse and one-third trash) has equivalent energy to 1.2 barrels of oil. Bioelectricity can be produced from bagasse, trash and dunder. Bioethanol can be produced from bagasse and trash. Biodiesel can be produced from an integrated sugar and bioethanol mill. He outlined a range of technologies under development that would help to achieve this vision.

The presentation also covered environmental sustainability and the need to reduce water consumption. His vision included the export of water and the production of fertiliser from concentrated dunder and filter mud.

*On line devices for process monitoring and control of the sugar production – the purity analyser (Mathis Kuchejda)*

Mathis Kuchejda indicated that the demand for on-line instrumentation came from the desire to maximise productivity through direct process control. On-line instrumentation is of great benefit in process control.

The on-line purity analyser measures purity according to the ICUMSA laboratory method. It consists of a process refractometer for measuring brix and a Polatronic NIR polarimeter for measuring pol. The NIR method does not require the juice to be clarified before measurement. The analyser can be used on process streams with brix from 15 to 85. Higher brix materials are diluted by a factor of four before measurement.

The instrument takes about 10 minutes to process a sample. It is intended that samples from multiple streams be processed by this one instrument. The system is cleaned as part of the measurement cycle in readiness for processing a different stream.

**Factory equipment design and manufacture**

*Keynote address: Factory equipment design and manufacture (Boris Morgenroth)*

After listing a range of emerging technologies for sugar mill equipment, Boris Morgenroth focussed on evaporator designs. He discussed the evolution of the evaporator, with falling film plate evaporators being the most recent type to gain acceptance. He indicated that this type of evaporator offered better heat transfer coefficients and less sucrose inversion but required higher juice velocities.
Concept for an energy efficient 6000 t/day cane sugar factory (Boris Morgenroth)

Boris Morgenroth described a range of technologies that he believed should be incorporated into a new cane sugar factory in order to achieve high energy efficiency. The technologies he recommended were:

- Diffuser technology and the return of clarifier underflow to the diffuser.
- Falling film plate evaporators.
- Increased fifth effect vapour temperature from 0.15 bar(a) to 0.55 bar(a).
- Vapour bleeding from all effects.
- All pans supplied with vapour 3 (about 100°C).
- Continuous pans for A, B and C products.
- A-seed cooling massecuite plant.
- Stepwise flashing of condensates and reuse of flash vapours.
- Using condensate for pre-heating of limed juice.
- High g-factor continuous centrifugals.
- High pressure boiler and turbo-alternator.
- High level of automation.

Simple innovative, proven equipment and processes for improving energy efficiency in sugar factories (Bruce Moor)

Bruce Moor discussed a range of relatively simple changes that could be made to an existing factory to improve energy efficiency. His baseline for improvement was a typical co-generating factory considered efficient in the 1980s. The technologies he discussed were:

- High steam pressure and temperature boilers.
- Continuous pans using vapour 2 or vapour 3.
- Diffusers.
- Mud recycling to diffuser.
- Electric drives on shredder and mills.
- Boilers with increased boiler efficiency (better air heaters and economisers) and less excess air.
- Direct contact heaters.

Long tube rising film evaporators, particularly for first and second effects.

Design, manufacturing and maintenance of sugar mill equipment (Simon Trancart)

Simon Trancart reported on a range of designs available from Fives Cail aimed at reduced maintenance costs and higher energy efficiency. These designs were:

- The in-line shredder which contains no knives and reduces power consumption by 15% to 20% as a result.
- The MillMax three-roll mill configuration that achieves 12% lower capital cost, 40% lower maintenance cost and 30% lower power consumption than an equivalent four-roll mill.
- A falling film tube evaporator that achieves high heat transfer coefficients, low residence time and low temperature drop.
- Two designs of continuous vacuum pan (one with vertical tubes and one with horizontal tubes) that can operate on vapour 2 or vapour 3, with low temperature drops.
- Batch centrifugals that consume 30–40% less power than earlier designs.
Main results of the application of planetary gear boxes to drive cane sugar mills (Paulo Rogério Vizin)

TGM have developed a range of planetary gearboxes for mills than enables in-line roll drives. The drives have been used to completely replace turbines or to provide assist drives to increase mill power through providing additional power on one roll. They can also be used to replace conventional gearing on turbine driven mills. The planetary gearboxes are more efficient than traditional mill gearing.

Characteristics of the Mexican industrial sugar plant – some innovations introduced (Manuel Enríquez Poy)

Manuel Enríquez outlined a range of technologies being introduced into the Mexican sugar industry to improve factory performance. These technologies were:

- 35 t trucks for cane transport.
- Heavy duty shredders.
- Hydrostatic mill drives and rope couplings instead of tailbars.
- Automatic roll arcing, including the pre-season application of picots for increased grip.
- Increased automation of the factory.
- Rotary juice screens.
- Bagasse bins.
- Automatic bagasse feeders for boilers.
- Higher pressure boilers.
- Low residence time clarifiers.
- Plate juice heaters.
- Pan automation.
- Continuous vacuum pans.
- Vertical crystallisers.
- Larger batch and continuous centrifugals.
- Cane separation for separate processing of pith and rind.
- Alcohol distilleries.
- Molasses storage in underground plastic liners.
- Liquid sugar and amorphous sugar.
- Bulk sugar road transport.

He also outlined a vision for a future mill that included ethanol production, cogeneration, use of vinasse for irrigation and mill mud for composting.

Computational modelling for the design of sugar mill equipment (Geoff Kent and Ross Broadfoot)

Geoff Kent and Ross Broadfoot provided a range of examples where the use of computational fluid dynamics had been used to improve the design of sugar mill equipment.

Specific examples included:

- Boilers.
- Juice clarifiers.
- Robert evaporators.
- Syrup clarifiers.
- Batch and continuous vacuum pans.
Development of pinionless mill for energy efficiency and low maintenance (D.K. Goel)

ISGEC John Thompson has developed a range of pinionless mills for up to 340 t/h cane rate. D.K. Goel outlined the design steps in developing the design and some of the design features of the mill.

The design included finite element analysis of the headstock, bearings and top roll assembly. The pinionless drives result in lower stresses in the components than in a conventional four-roll mill.

Other advantages include 15% lower cost, 15% lower power consumption, reduced lubricant consumption, more even top roll lift and reduced maintenance costs. One feature of this design is that the electric motors are vertically mounted to reduce the bending moment on the top roll shaft.

Design, manufacturing and maintenance of electro-hydraulic drives (Bo Ljung)

Bo Ljung described the characteristics of the electro-hydraulic drive. The drive has good speed control and full torque available over the entire speed range, up to the limit of the electric motor.

The maximum torque is determined from the size of the motor and the allowable hydraulic pressure. The maximum speed is determined from the capacity of the hydraulic pump.

Hydraulic motors have application in sugar mills as mill drives, conveyor drives, crystalliser drives and winch drives.

The drive features and maintenance requirements were described.

High pressure cogeneration in sugar plants (A.K. Subramanian)

A.K. Subramanian outlined the features of the high pressure boilers available from ISGEC John Thompson. He indicated that 32% higher power generation per tonne of bagasse could be achieved by increasing the boiler pressure from 45 bar to 105 bar.

The main features of the high pressure boiler are:

- Pressurised feedwater (220°C).
- Travelling grate to handle alternative fuels such as coal and woodchip.
- Electrostatic precipitators.
- On-line steam and water analysers.

In increasing the boiler pressure from 65 bar to 105 bar, the capital cost of a boiler increases by only 10%, due to the need to only change the design of the pressure parts. All boilers with a pressure greater than 45 bar require a dedicated water circuit.

Efficient cooling crystallisation – design and practice (Reinhold Hempelmann)

Reinhold Hempelmann described BMA’s oscillating vertical crystalliser design. The main feature of this design is that the cooling banks within the crystalliser move up and down by 1 m due to the action of hydraulic cylinders. This movement increases heat transfer and improves the flow of high-viscosity masssecuite. The crystalliser achieves plug flow, resulting in a well defined and consistent residence time.

Selection, use and maintenance of process pumps in sugar industry (Michael Yang)

Michael Yang described the selection criteria that should be used to select a centrifugal pump to minimise whole-of-life costs. These criteria include:

- Selection of the pump material and shaft sealing arrangement.
- Pumping efficiency (energy use).
- Maintenance costs.
- Quality.

Capital costs are only a significant part of whole-of-life costs for small pumps (less than 10 kW). Capital costs are almost negligible for pumps over 150 kW. Given the relative significance
of maintenance costs in the whole-of-life costs, stainless steel pumps with dynamic seals were recommended in most applications.

**Factory equipment maintenance**

*Keynote address: Condition monitoring (Alan Yarrow)*

The purpose of condition monitoring is to achieve a reduction in maintenance costs by only maintaining equipment that needs to be maintained. It assists to identify potential failures before they fail in order to reduce the incidence of breakdowns.

Alan Yarrow categorises items of plant as critical, moderate or convenient. Failure of critical plant could cause a major loss of production. Failure of moderate plant would cause some loss of production. Failure of convenient plant is not expected to cause a loss of production. The sampling frequency is highest for critical plant and generally only monitored at the end of the season for convenient plant (to determine if an overhaul is required during the maintenance season).

Typical techniques used for condition monitoring are:
- Vibration analysis.
- Oil analysis.
- Grease analysis.
- Use of a magnetic chip collector and filter debris analysis.
- Wear debris analysis.
- Thermography.

*Formalising maintenance processes with a traditional Australian sugar milling environment to develop a culture based on improvement (Steve Scott)*

Steve Scott outlined the process being undertaken at Harwood Mill in Australia to implement a maintenance management system in order to improve the operation of the plant and to reduce overall maintenance costs.

The process involved:
- Identifying the problems with the current maintenance system that expended all resources on immediate maintenance needs.
- Developing a maintenance management system.
- Formalising the control of maintenance work through work flow control.
- Analysing the effectiveness of maintenance in order to modify maintenance practices to increase the amount of scheduled maintenance and reduce the amount of unscheduled maintenance.
- Optimising maintenance schedules to minimise the amount of maintenance required.

*Wear mechanisms on shredder hammer tips (Geoff Kent)*

Geoff Kent described the results of an investigation to identify the wear processes in white iron and tungsten carbide shredder hammer tips. He reported that the main wear processes for white iron tips were matrix removal by plastic deformation, brittle fracture of the eutectic carbides adjacent to the surface and pull-out of eutectic carbides and secondary carbides adjacent to the surface. For tungsten carbide tips, the main wear processes were selective removal of the cobalt binder phase, loss of entire tungsten carbide grains and cracking and chipping of individual tungsten carbide grains.

*Sintered-tungsten carbide technology (Joydeep Duttagupta)*

Joydeep Duttagupta reported on a manufacturing process used by IMCO for manufacturing shredder hammer tips. The process involves producing a sintered carbide consisting of tungsten carbide blended with fused ceramics in a chrome matrix to form an alloy powder block. The arrangement was reported to increase crack resistance and extend life.
While the focus of the presentation was on shredder hammer tips, the technology has also been applied to leveller knives, trash plates, and shredder grid bars.

**Novel and unconventional equipment designs**

*Keynote address: Novel and unconventional equipment designs (Dave Meadows)*

Dave Meadows described the process for developing novel equipment designs. He indicated that there was a need for innovation to reduce costs, increase performance and increase safety. Design techniques include computer aided design, computer simulation and model validation using physical measurements. Design concepts were challenged, including whether large sizes and continuous processes are always better. The design process was described, including examples using current equipment designs.

*SRI swirl spreaders for improved boiler performance at increased loads (Geoff Kent)*

Geoff Kent described SRI’s swirl spreader that improves the distribution of bagasse over the furnace grate, increasing steam generating capacity by improving bagasse drying and reducing grate deposition. The design increases boiler capacity by at least 10%, improves flame stability and reduces the sensitivity to bagasse moisture content variations.

*The Siftek membrane technology (Normand Bernier)*

Vaperma have developed a revolutionary membrane system for alcohol distilleries. This system replaces the conventional rectification column and dehydration process and reduces energy consumption by up to 50%.

The technology is quite new, with two demonstration plants using corn-based feedstock and one demonstration plant now constructed in Brazil using sugarcane feedstock.

The system offers additional revenue from electricity due to the lower energy requirements for the plant, a continuous process and a flexible system allowing the production of both hydrous and anhydrous alcohol.

*The use of a novel jigger system to improve vacuum pan performance (Ross Broadfoot)*

Ross Broadfoot described a new jigger system for batch and continuous pans that uses incondensable gases injected in the base of a calandria to improve circulation and heat transfer.

He reported improvements in average circulation rates of up to 20%, a reduction in calandria pressure of 20 kPa to 40 kPa, improvements in heat transfer coefficients from 5% to 30%, reduced average steam flow and shorter cycle times.

The system is simple to install, requires little operator intervention and no special cleaning requirements.

*Development of cane dry cleaning in Brazil (Paulo Delfini)*

Paulo Delfini described the development of a dry cane cleaner in Brazil. Early experience found that it was difficult to predict the air flows within the cleaner, resulting in less than desired performance. Through the use of computational modelling, improvements were made.

To meet desired energy production requirements, Paulo Delfini indicated it is desirable to have trash contents in cane of about 13%. It is easiest to transport this trash with the cane and then separate the trash at the factory. Once separated, the trash can be washed if desired and returned to the process. Several examples of dry cleaning installations where the trash was returned to the process before the final mill and mixed directly with final bagasse were described.

**Closing session**

The author gave a brief summary of the outcomes from the workshop in the closing session. In particular:

- Several speakers articulated a shared vision of the future of the Brazilian sugar industry. This shared vision gives considerable confidence that the vision can become a reality.
There is an increased focus on energy products. As a result, the reduction of factory energy consumption in order to maximise the energy available for products is also a focus.

New equipment and products are being developed with reduced power consumption, lower capital and maintenance costs and better performance.

Methods presented for reducing maintenance costs included the use of a maintenance management system, condition monitoring and material selection.

Site visits

The workshop included four site visits:

1. TGM. The visit included TGM’s gearbox manufacturing plant and turbine manufacturing plant. The gearbox manufacturing plant produces a wide range of conventional and planetary gearboxes of 85 kN.m to 4000 kN.m capacity. The turbine manufacturing plant produces a wide range of turbines of capacity up to 250 MW.

2. Usina Mandú. This sugar factory and distillery processes about 12 000 t cane per day. There are a large number of TGM gearboxes on the milling train.

3. Usina Da Barra. This large white sugar factory and distillery processes 38 000 t cane per day. It produces a range of white crystal, amorphous and liquid sugar.

4. Dedini. The factory visited is one of Dedini’s six large manufacturing facilities, specialising in the design and construction of complete sugar factories and distilleries, in addition to individual items of plant. It also services other industries such as breweries, mining and steel.
CONCEPTION, MANUFACTURE ET MAINTENANCE DES ÉQUIPEMENTS

Par

G.A. Kent
Président de la Section d'Ingénierie de ISSCT

MOTS-CLES: Sucre, Mill, Appareils d'Usine de Sucre, Conception, Fabrication, Maintenance.

Résumé
L’ATELIER de la section Engineering de l’ISSCT a eu lieu au Brésil; 62 délégues étaient présents, 39 représentant des visiteurs de 15 pays. Le sujet a été «Conception, manufacture et maintenance des équipements». On a conclu comme suit: plusieurs auteurs ont présenté une vision pour le future de l’industrie au Brésil; on pense que cette vision peut se réaliser; l’énergie et son utilisation pour d’autres produits sont des sujets très importants. Il faut réduire son utilisation à la sucrerie; on développe des équipements et des produits nouveaux pour réduire la demande d’énergie, les coûts et pour augmenter l’efficience. On a présenté des systèmes pour réduire le coût de la maintenance. L’atelier a eu lieu pendant l’exhibition annuelle SIMTEC pour l’industrie sucrière et celle de l’alcool; cela a permit des discussions et présentations techniques et des démonstrations de matériel industriel. SIMTEC a contribué en aidant financièrement et en organisant l’atelier. Les programmes techniques de SIMTEC et de l’ISSCT ont été organisés pour faciliter la participation des délégues aux sessions techniques des deux organisations. On a ajouté une journée au programme de l’ISSCT pour permettre aux délégues de visiter l’exhibition SIMTEC. Les arrangements entre SIMTEC et ISSCT ont été appréciés par les délégues. Deux manufactures et deux sucreries ont été visitées.
ISSCT WORKSHOP DE INGENIERÍA 2008. DISEÑO, MANUFACTURA Y MANTENIMIENTO DE EQUIPOS DE INGENIOS AZUCAREROS

Por

G.A. KENT
Presidente de la Sección de Ingeniería ISSCT

PALABRAS CLAVE: Azúcar, Mill, Aparatos de Molino de Azúcar, Diseño, Fabricación, Mantenimiento.

Resumen

El WORKSHOP de Ingeniería ISSCT 2008 en Brasil contó con la asistencia de 62 participantes incluyendo 39 visitantes extranjeros de 15 países. El evento se orientó al tema Diseño, manufactura y mantenimiento de equipos para ingenios azucareros. Las siguientes conclusiones se obtuvieron de las sesiones técnicas: Varios conferencistas articularon una visión compartida del futuro de la industria azucarera de Brasil; Esta visión compartida da confianza en que la visión pueda volverse realidad; Hay un creciente interés en productos energéticos. Como resultado, también hay gran interés en la reducción del consumo de energía en la fábrica para maximizar la energía disponible para productos. Equipos y productos nuevos están siendo desarrollados con menores consumos de potencia, menores costos de capital y de mantenimiento y con mejor desempeño. Los métodos presentados para la reducción de costos de mantenimiento incluyeron el uso de sistemas de gestión de mantenimiento, monitoreo del estado de equipos y selección de materiales. El Workshop se desarrolló conjuntamente con la exhibición anual de SIMTEC en Piracicaba para la industria de azúcar y etanol y se generó un foro para las presentaciones técnicas y las discusiones así como una oportunidad para las demostraciones y ofertas de servicios de los fabricantes y proveedores de equipos. Como contrapartida, SIMTEC brindó patrocinio para el evento, incluyendo viaje y alojamiento para los presentadores. Los programas técnicos de ISSCT y SIMTEC se organizaron de tal manera que las sesiones no entraran en conflicto y el programa de ISSCT se extendió un día para brindar a los participantes la oportunidad de asistir a la exhibición de SIMTEC. Una evaluación informal con los participantes sugirió que la asociación de los eventos de ISSCT y SIMTEC funcionó bien. Se efectuaron visitas a dos instalaciones de fabricación de equipos y a dos ingenios como parte del evento.
SUGAR MILL OPERATION WITH INDIVIDUAL DRIVES

By

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KEYWORDS: Hydraulic, Mill, Drive, Independent, Torque, Speed.

Abstract
THE TERM ‘Individual drives’ refers to the process of separately moving each roll of the mill with independent drives. This way of mill operation is rather new and knowledge regarding how to set and operate the mills with individual drives is very limited. This paper describes tests made with a complete tandem (four mills) driven by electro-hydraulic independent drives. The first mill was driven at a constant top roll speed, and the feeding was adjusted automatically to keep the chute level within the determined range. The rest of the mills were automatically changing speed, keeping the chute level of the corresponding mills within the pre-established range. Three scenarios were analysed in the first tests: speed ratio between side and top rolls varied to keep the same pressure in all hydraulic systems (torque distribution 50, 25, 25% between top, cane and bagasse rolls respectively), speed ratio to keep the same peripheral speed for each roll and rotational speed ratio equal to 1 as is often the case with conventional drives. For each scenario, the torque and power distribution were measured. The main conclusions found were that the total torque required doesn’t depend on the speed of the mill for constant mill pressure and that the distribution of the torque in the four-roll mill can be 50, 25, 25 for higher speed of the cane roll and lower speed of the bagasse roll than the top roll speed. This scenario is best from a mechanical and operational point of view.

Introduction
The term ‘Individual direct drives’ refers to the separate propulsion of each mill roll by a drive placed directly on the shaft of each roll.

The first mill drive using this method was reported in Cuba (Abon, 1986) where the torque distribution between the rolls, depending on the relative speeds of the side rolls compared to the top roll, was presented.

This installation was the result of the collaboration of MINAZ (Ministry of Sugar) and the Hägglunds company, starting with the introduction of the first high torque hydraulic motors in Cuba in 1976.

For that first installation, the drive was formed by combining Hagglunds hydraulic motors with two-stage planetary gearboxes of the Thyssen company.

This concept gave rise to the ‘Hydrodrive’ of the Mannesmann Rexroth company, where high speed hydraulic motors and three-stage planetary gearboxes were combined.

A similar installation was analysed in Mexico 10 years later (Muñoz and Lewinski, 1996) and important research about the torque distribution in three-roll sugar mills was carried out in Australia (Kent and McKenzie, 2001).

In the 1980s, Hägglunds developed higher torque hydraulic motors, allowing mill rolls to be driven individually, and eliminating the need for planetary gearboxes.
At the same time, the German company Flender, well known manufacturer of gearboxes, presented a ‘Hydrex – Planurex’ system, combining a high torque hydraulic motor of their own manufacture and a one-stage planetary gearbox.

These high torque hydraulic motors, with and without planetary gearboxes, were very well received in the marketplace, due to the following advantages:

1. Partial or full elimination of conventional gears and crown gears.
2. Elimination of the tail bar.
3. Less space required.
4. Reduction of loads on roll shafts.
5. No foundation required.
6. Maximum torque over the full speed range; from zero to maximum speed.
7. Reversible movement.
8. Continuous speed variation in each roller.
9. Protection against overloading and almost immediate interruption of mill operation.
10. Simplifies automation of the milling process.
11. Measurement of the torque for each roller.
12. Easy maintenance.
14. Power savings (high efficiency in transmission, use of electric power, load reduction in journal bearings).
15. Increased extraction (optimisation of the extraction process).

The main advantage is the independent variable speed of each roll, which allows for the optimisation of the mill’s operation from a mechanical (torque distribution) and operational point of view (extraction, pol in bagasse, moisture in bagasse) (Lewinski, 2005; Vivas et al., 1998)

A more recent alternative for fitting individual drives to sugarcane mills has been the use of planetary gearboxes engaged directly to or through the cardan shaft with AC electric and variable frequency motors, a well known solution in the sugarcane industry for driving cane conveyors.

Currently the following options are commercially available for mill operation on an individual basis.

1. Electro-hydraulic drive – high torque, low speed hydraulic motor
2. Electro- hydraulic – mechanical drive (high torque, low speed hydraulic motor connected to a one-stage planetary gearbox)
3. Electro – hydraulic – mechanical drive (medium speed hydraulic motor with a two-stage planetary gearbox)
4. Electro – hydraulic – mechanical drive (high speed hydraulic motor with a three-stage planetary gearbox)
5. Electro mechanical drive (planetary gearbox driven by an AC variable frequency electric motor.

At present, options 1 and 5 are the most common ones in the market.

Although 20 years experience has been gained operating mills with direct, individual drives, there is no published information on how to operate these mills (torque distribution, speed distribution, mill adjustments, etc.). This work aims to answer some of these questions.

**Description of the testing methodology**

Tests were conducted on a mill tandem driven by high torque electro-hydraulic drives, without planetary gearboxes.
Each mill was driven by four high torque hydraulic motors of the same size, directly placed on the mill’s rolls (two motors on the top roll and one on each side roll) (Figure 1).

Each hydraulic motor was powered by an electric motor which drove a variable flow hydraulic pump, allowing for the operation of the motors at rated torque over the whole speed range. The flow was transmitted to the motors through piping, which allowed for great flexibility of positioning for the power units (electric motor, pump and accessories) in relation to the hydraulic motors. The tandem was made up of four mills and was located in the Santa Isabel sugar mill, in Brazil (Figure 2).

Mill 1 had a length of 2134 mm and the remaining mills were 1981 mm in length. The mills were set for a cane rate of 550 t/h and operated at constant first mill speed, usually 6 r/min. The tandem was automated (Figure 3).

The feed of mill 1 was controlled to maintain the level of the chute in the determined range and the other mills varied their speed automatically to maintain the level of their chute within the predetermined ranges. Measurements included the torque on each mill’s shaft (continuous pressure measurement for each hydraulic system) and speed (sensors placed directly on the hydraulic motors).
Desired results were:
1. Torque distribution.
2. Speed distribution (ratio of speed of the side rolls in relation to the top roll).
3. Distribution of power on the mill’s rolls.
4. Total power consumed by each mill.

In the first tests carried out in 2008 in Santa Isabel Sugar Mill, three different scenarios were analysed for the mill settings defined by the manufacturer.
1. Distribution of torque 50%, 25%, 25% between the top, cane and bagasse rolls respectively - providing optimal capacity performance of the hydraulic motors (equal pressure on all hydraulic systems of the mill). For this scenario, the speed ratios were experimentally determined).
2. Equal peripheral speeds for all mill rolls – a case considered by several researchers as optimal for mill operations.
3. Equal rotational speed for all mill rolls – as is often the case of mills with conventional transmissions equipped with pinions.

Further tests were carried out in 2009 in Santa Isabel for the purpose of measuring the torques and powers in all mills of the tandem. These tests were conducted for the first scenario of equal pressures in all hydraulic systems.

Results
Measurements were taken during two test periods, identified as Test 1 and Test 2. Within these periods, each of the three scenarios was used. The periods for the individual measurements are shown in Table 1.

<table>
<thead>
<tr>
<th>Test</th>
<th>State</th>
<th>Scenario</th>
<th>Mill 1 speed (r/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>1</td>
<td>II</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>III</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>IV</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>V</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>I</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>II</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>III</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>IV</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>V</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>
As an example of the results, Figure 4 shows the results for mill 1 for Test 1 and Figure 5 shows the results for mill 4 for Test 2. In the legends for these two figures, ‘TR’ refers to top roll, ‘CR’ refers to cane roll and ‘BR refers to bagasse roll while ‘r.p.m.’ refers to speed and ‘Bar’ refers to hydraulic motor pressure.

Table 2 presents the mean results for each state for each mill. ‘SR’ in the title refers to speed ratio of the nominated roll to the top roll. Table 3 presents the mean power for each mill and each state with a mill 1 speed of 5 rpm.
Table 2—Mean results for the 2008 tests.

<table>
<thead>
<tr>
<th>State</th>
<th>Pressure</th>
<th>Speed</th>
<th>Torque</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>TR</td>
<td>BAR</td>
<td>TR R/min</td>
<td>CR</td>
<td>SR</td>
</tr>
<tr>
<td>MILL 1</td>
<td>1</td>
<td>174</td>
<td>174</td>
<td>171</td>
</tr>
<tr>
<td>TEST 1</td>
<td>11</td>
<td>178</td>
<td>181</td>
<td>182</td>
</tr>
<tr>
<td>IV</td>
<td>179</td>
<td>146</td>
<td>197</td>
<td>5.0</td>
</tr>
<tr>
<td>V</td>
<td>178</td>
<td>133</td>
<td>214</td>
<td>5.0</td>
</tr>
<tr>
<td>MILL 1</td>
<td>II</td>
<td>188</td>
<td>184</td>
<td>172</td>
</tr>
<tr>
<td>TEST 2</td>
<td>IN</td>
<td>197</td>
<td>135</td>
<td>188</td>
</tr>
<tr>
<td>IV</td>
<td>195</td>
<td>121</td>
<td>203</td>
<td>5.0</td>
</tr>
<tr>
<td>V</td>
<td>187</td>
<td>180</td>
<td>184</td>
<td>5.0</td>
</tr>
<tr>
<td>MILL 2</td>
<td>II</td>
<td>195</td>
<td>194</td>
<td>190</td>
</tr>
<tr>
<td>TEST 2</td>
<td>III</td>
<td>198</td>
<td>185</td>
<td>189</td>
</tr>
<tr>
<td>IV</td>
<td>190</td>
<td>189</td>
<td>193</td>
<td>5.5</td>
</tr>
<tr>
<td>V</td>
<td>192</td>
<td>162</td>
<td>201</td>
<td>5.6</td>
</tr>
<tr>
<td>MILL 3</td>
<td>II</td>
<td>198</td>
<td>203</td>
<td>192</td>
</tr>
<tr>
<td>TEST 2</td>
<td>11</td>
<td>194</td>
<td>199</td>
<td>195</td>
</tr>
<tr>
<td>IV</td>
<td>192</td>
<td>186</td>
<td>197</td>
<td>5.0</td>
</tr>
<tr>
<td>V</td>
<td>188</td>
<td>171</td>
<td>212</td>
<td>5.1</td>
</tr>
<tr>
<td>MILL 4</td>
<td>II</td>
<td>189</td>
<td>194</td>
<td>196</td>
</tr>
<tr>
<td>TEST 2</td>
<td>II</td>
<td>190</td>
<td>192</td>
<td>195</td>
</tr>
<tr>
<td>111</td>
<td>188</td>
<td>175</td>
<td>198</td>
<td>4.8</td>
</tr>
<tr>
<td>IV</td>
<td>185</td>
<td>159</td>
<td>210</td>
<td>4.9</td>
</tr>
<tr>
<td>V</td>
<td>189</td>
<td>170</td>
<td>206</td>
<td>5.1</td>
</tr>
</tbody>
</table>

Table 3—Mean power for the whole tandem.

<table>
<thead>
<tr>
<th>R/min</th>
<th>State</th>
<th>Power kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mill 1</td>
<td>114</td>
<td>821</td>
</tr>
<tr>
<td>Mill 2</td>
<td>115</td>
<td>800</td>
</tr>
<tr>
<td>Mill 3</td>
<td>4</td>
<td>793</td>
</tr>
<tr>
<td>Total tandem</td>
<td>114</td>
<td>843</td>
</tr>
</tbody>
</table>

Laboratory results for the day in which Test 1 and Test 2 were conducted were as follows: cane rate 572 t/h and extraction 95.65%.

The first scenario where the speed ratio was adjusted to keep the same pressure in all hydraulic systems was assessed to be the most suitable, taking into account the optimal use of the drives, as well as the distribution of speed. In this tandem, the cane roll always rotates at a higher speed helped by the better feed and the bagasse roll usually rotates at a lower speed. The torque on
the top roll was generally constant, independent of the speed variations of the mill and the speed ratios and, as a result of the control scenario, was 50% of the total torque generated.

Table 4 presents results of measurements carried out in Santa Isabel in 2009. Both tests used scenario 1 with equal pressure in all hydraulic systems – torque distribution 50, 25, 25.

Figure 6 shows the mill 1 results for Test 2 and Figure 7 shows the mill 4 results for Test 2.

**Table 4**—Numerical mean results for the whole tandem in 2009.

<table>
<thead>
<tr>
<th>Mill number</th>
<th>Test</th>
<th>Pressure</th>
<th>Speed</th>
<th>Torque</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>TR Bar</td>
<td>CR Bar</td>
<td>BR Bar</td>
<td>TR r/min</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>156.2</td>
<td>164.5</td>
<td>165.9</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>158.1</td>
<td>162.0</td>
<td>155.5</td>
<td>6.5</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>156</td>
<td>158</td>
<td>169</td>
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<td>162</td>
<td>156</td>
<td>162</td>
<td>6.70</td>
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<td>3</td>
<td>1</td>
<td>156</td>
<td>162</td>
<td>169</td>
<td>6.20</td>
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<td>153</td>
<td>161</td>
<td>155</td>
<td>6.30</td>
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<td>149</td>
<td>164</td>
<td>6.10</td>
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<tr>
<td></td>
<td>2</td>
<td>156</td>
<td>155</td>
<td>161</td>
<td>6.10</td>
</tr>
<tr>
<td>Total tandem</td>
<td>1</td>
<td>2626</td>
<td></td>
<td></td>
<td></td>
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<td>2</td>
<td>2622</td>
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</table>

**Fig. 6**—Mill 1 Test 2 results from the 2009 tests.
Fig. 7—Mill 4 Test 2 results from the 2009 tests.

The laboratory results demonstrated higher milling capacity (cane rate 591.3 t/h) and higher extraction (96.76%) in comparison with the 2008 results with very similar or even slightly lower total power consumed by the tandem. The extraction only from the Mill 1 was close to 84%. In comparison with 2008, all the rolls were machined reducing their diameter by 30 mm, the mill pressure was kept at the same level, and the settings of the mills were made very close to the values from the year 2008. The mill rotational speed was higher to maintain similar tangential speed of the rolls as in 2008 (Sato, 2009).

Conclusions

With the individual drives, mills can be operated at different speed distributions, giving the possibilities to drive the mill with the same tangential speed of the rolls, the same rotational speed as in conventional mills and changing the ratio between side and top rolls looking for the higher cane roll speed (for better feeding) and lower bagasse roll speed (for lower reabsorption).

This last option was achieved for similar mean pressures in all hydraulic motors, resulting in the same torque applied on the end of all the shafts. For this option all hydraulic drives can be operated at their maximum capacity, maximising the mill torque, avoiding the hydraulic system overloading, giving the same stresses on the end of all the shafts.

At Santa Isabel Sugar Mill, the use of the equal pressure control scenario helped to give better milling results than the previous year. The tandem of four mills is now achieving a cane rate close to 600 t/h and extraction of 97%, with extraction from mill 1 close to 84%. These better results were achieved with total mill power consumption about the same as in the previous year.

Acknowledgements

The authors would like to express their gratitude to the companies Hagglunds Sweden and Hagglunds Brazil for the interest in this research and the corresponding economical support. Thanks to Santa Isabel Sugar Mill people for their support and great cooperation in making possible this
research. Thanks to Mr Mario Sato for the permission to use his settings in Santa Isabel Sugar as reference. Special thanks to Geoff Kent for his very valuable comments and observations and for great help in interpreting the results and preparation of the last version of this paper.

REFERENCES


OPÉRATION DE MOULINS À SUCRE
AVEC COMMANDE INDIVIDUELLE

Par

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MOTS-CLEFS: Hydraulique, Moulin, Commande, Indépendant, Couple, Vitesse.

Résumé

Le terme « commande individuelle » indique que chaque rouleau du moulin est conduit indépendamment. Ce mode de fonctionnement est nouveau et les connaissances le concernant sont très limitées. Ce document décrit les tests réalisés sur un tandem complet (quatre moulins) conduit par des moteurs indépendants electro-hydrauliques. Le premier moulin a été conduit à une vitesse constante pour le cylindre supérieur et l'alimentation a été ajustée automatiquement pour maintenir le niveau de la goulotte dans la plage déterminée. Le reste des moulins modifient leurs vitesses automatiquement pour maintenir le niveau des goulottes correspondantes dans les plages préétablies. Trois scénarios ont été analysés dans les premiers tests: le rapport des vitesses cylindres de côté et supérieur est varie pour maintenir la pression constante dans tous les systèmes hydrauliques (distribution du couple 50, 25, 25% entre les rouleaux supérieur, canne et bagasse respectivement), rapport de la vitesse sélectionne pour conserver la même vitesse périphérique pour chaque rouleau et le rapport de la vitesse de rotation égal à 1 comme c'est souvent le cas avec les conduites conventionnelles. Pour chaque scénario, le couple et la distribution de la puissance ont été mesurés. Les principales conclusions trouvées étaient que le couple total requis ne dépend pas de la vitesse du moulin à une pression constante et que la répartition du couple dans un moulin avec quatre cylindres peut être 50, 25, 25 pour une vitesse supérieure du cylindre canne et une vitesse inférieure pour le cylindre bagasse compare à la vitesse du cylindre supérieur. Ce scénario est le meilleur d'un point de vue mécanique et opérationnel.
OPERACIÓN DE MOLINOS DE CAÑA CON ACCIONAMIENTOS INDIVIDUALES

Por

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PALABRAS CLAVE: Hidráulica, Molino, Accionamiento, Torque, Velocidad.

Resumen

EL TÉRMINO accionamiento individual se refiere al movimiento de cada maza de un Molino de caña con accionamientos independientes. Esta forma de operación es relativamente nueva y el conocimiento sobre cómo ajustar y operar estos molinos es limitado. Este trabajo describe las pruebas efectuadas con un tándem completo (cuatro molinos) movido por accionamientos electrohidráulicos independientes. El primer molino fue accionado a velocidad constante de la maza superior y la alimentación se reguló automáticamente para mantener la altura de la caña preparada en la tolva del molino dentro del rango determinado. El resto de los molinos operaron con velocidad variable para mantener la altura de bagazo en la tolva de cada Molino dentro del rango especificado. Tres escenarios fueron analizados en las primeras pruebas: la razón de velocidades entre maza superior y las inferiores se varió para mantener la misma presión en todos los sistemas hidráulicos (distribución de torque de 50, 25, 25% entre mazas superior, cañera y bagacera respectivamente), la razón de velocidades para mantener la misma velocidad periférica para cada maza y razón de velocidades igual a 1 como es a menudo el caso en accionamientos convencionales. Para cada escenario, se midieron el torque y la distribución de potencia y las principales conclusiones encontradas fueron que el torque total requerido no depende de la velocidad del molino para presión de molienda constante y que la distribución porcentual del torque en un molino de cuatro mazas puede ser 50, 25, 25 para relaciones de velocidad entre maza cañera y superior mayores que 1 y entre maza bagacera y superior menor que 1. Este escenario es el mejor desde un punto de vista mecánico y operacional.
THE IMPLEMENTATION OF SOUTH AFRICAN SUGAR TECHNOLOGY:
THE WORLD’S LARGEST SUGARCANE DIFFUSERS

By

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KEYWORDS: Diffusers, Extraction, Brazil,
Technology, Chainless, South Africa.

Abstract
Cane diffusion gained popularity in South Africa in the 1960s and 1970s using European technology. Local research and developments led to the development of locally designed diffusers and to the South African industry achieving the highest extraction rates in the world. The largest diffusers in the South African industry were installed at Felixton 2 in 1984, being 12 metres wide and rated (conservatively) at 350 t/h. The first real change to the fundamentals of diffuser design since then took place when Bosch Projects introduced the ‘chainless diffuser’ concept in 2006. Of the nine chainless diffusers to be installed in Brazil between 2008 and 2010, two are similar in size to those at Felixton and six are larger. The first of the 12 metre diffusers (at UNP and rated at 500 t/h) was commissioned in September 2008. The diffusers at Brenco, Cosan Jatai and Meridiano are 15 metres in width, are rated for 98% extraction at 625 t/h and will be the largest cane diffusers in the world. The diffusers in Cosan and Meridiano will ultimately process 875 t/h. The successful sales of the chainless diffuser in Brazil is evidence that South African sugar technology and engineering continue to play a leading role, even in the most competitive sector of a fast-changing world industry.

The history of cane diffusers
It is reported that cane diffusion has been in use for over 100 years, first in batch form and more successfully as a continuous process. Continuous diffusers were well accepted in the beet industry before they made their way into the cane industry. Their acceptance in the cane industry became more common in the 1960s, first as bagasse diffusers (where one or two mills preceded the diffuser) and then later as cane diffusers.

As an indication of the increasing interest in this alternative extraction technology at the time, the proceedings of the 12th Congress of the ISSCT in Puerto Rico in 1965 contains numerous papers by researchers and engineers reporting on early continuous diffusers around the world.

- The Diaz-Compain diffuser, from a Puerto Rican designer, was working in a factory in East Pakistan. (Diaz-Compain, 1966). The principle of operation was to fully submerge the cane in a very large slat conveyor, and rates of extraction of over 99% were claimed.
- The first DDS cane diffuser had been operating for a few months at TPC in Tanganyika (Weng and Bruniche-Olsen, 1966). It was based on the DDS beet diffuser and consisted of twin screw conveyors that transported the bagasse counter-current to the juice. Clarifier mud was recycled to the diffuser.
- A Silver Ring diffuser was reported as operating in its second season in Hawaii (Townsley and Cheatham, 1966). This was a hugely successful installation and their understanding of the important requirements for successful diffusion was years ahead of its time, as reported by Payne (1968).
E. Gulbaran (Turkey) proposed his diffuser for cane and beet (Gulbaran, 1966).

The operating results from three 150 tch bagasse diffusers at Nag Hamadi in Egypt were presented, while a 200 t/h unit was under construction. (Tantawi, 1966). The Egyptian diffusers were of the style that ultimately became popular in South Africa, using a stationary perforated plate floor; chains for the conveyance of bagasse inside the diffuser; a 1–2 m bed depth at 0.7–1.5 metres per minute; and independent juice collecting tanks below the screen.

In South Africa, diffusion started in 1927 when Duncan Fletcher supplied a diffuser to the Tinley Manor factory (Buck, 1965). In 1966, Union Co-operative installed a BMA bagasse diffuser in their new sugar factory based on the very promising performance of the Egyptian diffusers, and De Smet diffusers were installed at Entumeni and Nchalo (Buck, 1965). In 1967, a BMA diffuser was installed at Empangeni mill and a De Smet diffuser at Malelane. (This was a period of substantial growth in the industry, and new milling tandems were commissioned at Amatikulu, Noodsberg and Sezela) (Perk, 1966).

By 1974, there were seven diffusers operating (or under construction) in the industry as follows (Fitzgerald and Lamusse, 1974):

- Union Co-op: 60 t/h BMA bagasse diffuser (1966).
- Empangeni: 205 t/h BMA bagasse diffuser (1967).
- Malelane: 225 t/h De Smet bagasse diffuser (1967).

By 1984, there were 10 cane diffusers and four bagasse diffusers in the SA industry out of 21 extraction plants, accounting for 54% of cane processed (Lamusse, 1985). In these early days, the motivation for installing diffusers was the lower capital cost and lower costs of maintenance and operations (Fitzgerald and Lamusse, 1974), rather than improved extraction, since the early extraction benefits were small.

An interesting historical phenomenon is that, while the installation of new diffusion plants and their successes are well documented, the reasons for their failures are not so well recorded. Of the list of seven diffusers in 1974, only Amatikulu remains. The bagasse diffuser at Union Co-op was replaced with a cane diffuser; the Entumeni and Empangeni factories were ultimately closed; Malelane now has a BMA cane diffuser, as does Pongola; and Umfolozi has a De Smet diffuser.

**Diffuser development in South Africa**

In the early days of this boom in diffusion, South African engineers contributed significantly to the success of the technology, whereas a lack of engineering innovation seems to have doomed diffusers to failure elsewhere. Renton and van der Riet (1971) reported on the improvements made to the 225 t/h BMA diffuser at Huletts’ Empangeni mill, which was installed to replace the third and fourth mills of their six mill tandem. Huletts pioneered the use of:

- lifting screws to overcome the problems of flooding in the area of press water return;
- tracer testing of juice percolation using NaCl and the adjustment of stage troughs;
- the use of stage sprays in place of overflow troughs;
- windows for internal observation of the diffuser;
- the elimination of press water clarification;
- the use of two dewatering mills in parallel with each other;
- the use of scraper slats on diffuser chains;
using water as ballast in the press roller;
• an improved understanding of cane preparation requirements.

In the mid-1970s the FS/van Hengel diffuser was developed, claiming advantages of:
• modular construction allowing for incremental capacity increases;
• lower residence times;
• increased sucrose extraction;
• reduced floor area.

Huletts engineers contributed significantly to the theoretical understanding of the diffusion process. Rein (1974, 1995) and Love and Rein (1980):
• quantified the relationship between cane preparation and extraction;
• studied percolation patterns and juice hold-up;
• quantified the effect of stage juice recirculation, imbibition water rate, temperature and residence time on extraction;
• developed a means of controlling diffuser flooding by measuring the juice level inside the bed;
• quantified the proportion of work done by lixiviation versus molecular diffusion.

The diffusers developed by Tongaat Hulett incorporated some unique features (Moor, 2001 a,b):
• Diffuser dry feeding, eliminating the problematic segregation of fines which was caused by conventional sluiced feeding.
• The elimination of draft juice screening.
• The use of direct contact heating of unscreened press water.
• the introduction of fully adjustable juice sprays (replacing weirs).
• and juice level measurement for automatic spray positioning.

In 1996, Bosch Projects rekindled interest in the old idea of clarifier mud recycling (and branded it ‘Filtrafusion’). Tongaat Hulett trialled the process at its Maidstone factory (Meadows et al., 1998). This proved successful and has since become the standard for diffusers in South Africa.

As a result of many years of focus on the optimisation of diffuser design and operation, the extraction achieved by Southern African mills exceeded all previously accepted norms. The average extraction of diffuser factories in South Africa frequently exceeds 98% over the entire season.

**The advantages of diffuser extraction over milling**

The rapid adoption of diffusers in South Africa was as a result of many benefits (Rein, 1995; Koster, 1995; Hoeskstra, 1995). Compared to milling, diffusers:
• achieve better extraction results;
• have a lower capital cost;
• are cheaper to maintain and operate;
• absorb less power;
• result in a factory with lower HP steam demand, making more HP steam available for the generation of electrical power.

**The limitations of diffusers**

Despite the remarkable success achieved in South Africa, diffuser technology never made a lasting impact elsewhere. Cane diffusers were installed far and wide – both BMA and De Smet were very successful internationally. However, although the technology was introduced in most growing sugar industries, it never reached the point of domination over milling extraction, as it had
in South Africa, despite the obvious benefits of improved extraction, lower capital cost, lower maintenance and operational costs and improved energy efficiency. The reasons for this vary from country to country and can be fairly difficult to establish. However, the following anecdotal reasons have been given:

- The cane preparation requirements are more demanding for diffusers than mills, and a heavy-duty shredder is essential. This adds to the initial cost of cane preparation equipment and also to the absorbed power for cane preparation.

- It is widely believed that diffusers require higher imbibition water rates than mills, and hence additional exhaust steam demand and evaporator capacity. This is probably because of the high rates used in South Africa, but does not consider the fact that South African imbibition water rates can be high because of excess available bagasse due to long milling seasons, good time efficiencies, high fibre content in cane and the reduced demand for HP steam because of the diffusers in operation.

- In South Africa, we take for granted the sharing of experiences through forums such as the annual SASTA Congress; research performed for the industry by the SMRI; and the constant drive for improved factory efficiencies to compensate for low agricultural yields. In this environment, technological advances in one factory are rapidly communicated and adopted in others, with a good probability of further improvements. Not all countries have a similar structure and culture. For example, in Brazil, factories have traditionally been owned by family concerns and the promotion of new technologies is largely through equipment suppliers. In India, a large proportion of factories were traditionally co-operatives or state-owned, with few incentives to develop technology.

- In countries with milling seasons shorter than that of South Africa, the cane crop is not necessarily large enough to justify the capital expense of more than four mills in a tandem. In these cases, the capital cost of a four mill tandem is compared with that of a diffuser and two de-watering mills, and the economic benefits become more marginal. Not considered is the fact that a smaller and cheaper diffuser could be used for extraction equivalent to four mills.

- The concern that, once a diffuser has been built, its capacity is determined. Any future expansion of the capacity is difficult and costly.

The latter point is, in the experience of the author, the most oft-quoted reason for diffusion not being more readily accepted in industries that have experienced growth.

The reason for the limited expandability of moving bed diffusers rests in the fact that a diffuser’s capacity is related to its dimensions—a larger diffuser can process more cane than a smaller diffuser at the same extraction performance. However, the length of a diffuser is constrained by the limit of chain tension allowed.

Also, any extension to a diffuser’s length will normally require the repositioning of cane preparation equipment or de-watering mills. The height of a diffuser is limited by the depth of prepared cane through which juice can practically percolate. The variable dimension is thus the width of a diffuser, and diffuser capacities are determined by their width. In Brazil, a very simple rule-of-thumb is used to define a diffuser’s capacity: 1 metre of width = 1000 tonnes of cane per day (assuming 100% availability).

(The discussions regarding expandability are generalisations. The diffuser at Triangle in Zimbabwe was expanded to operate at 1800 mm bed depth, and the diffuser at Amatikulu was lengthened by 9.5 metres. However, it is quite obvious that, in both cases, further expansions in capacity are unlikely.)
Every moving bed diffuser has a head shaft at the discharge end of the diffuser. The headshaft drives the diffuser chains and is a rather heavy piece of engineering. (The headshaft of a 12 metre wide diffuser has a mass of about 100 tonnes.) More than any other, this is the component that limits the expandability of diffusers since, for any increase in the width of a diffuser, the headshaft must be replaced with a longer shaft. The economics thereof generally make such an expansion infeasible. Furthermore, in all traditional diffuser designs, the return of the chains is beneath the diffuser, which thus requires a substantial bridging structure, the extension of which is extremely costly.

**How wide should a diffuser be?**

As previously stated, the capacity of a diffuser depends on its size. The parameters considered for a specified performance are:

- Screen area/tonnes fibre per hour. For extraction performance of 98%, this parameter is in the range of 11–12 m²/t fibre/h.
- Bagasse retention time. For top performance, 70–80 minutes is considered suitable.

Given an assumed bed depth and an assumed bed speed, these parameters determine the diffuser length and width. The chainless diffusers have a standardised length of 60.25 m, a bed speed of 0.75 m/min and a bed height of 1.5 m. Given these parameters, the conventional width of a chainless diffuser is 5.4 t fibre/h per metre width or 4 t fibre/h per module. Other diffuser designers have different parameters.

**How the chainless diffuser eliminates size constraints**

The chainless diffuser concept was developed in 2006 when it was installed into the existing BMA diffuser at UCL (Schröder et al., 2007).

The chainless diffuser eliminates the need for chains and a diffuser headshaft. Instead, the diffuser screen (floor) consists of 750 mm wide modules that run the entire length of the diffuser. Each of these modules moves independently of each other, and by employing the correct sequence of movement the cane is conveyed through the diffuser. These individual modules are actuated by hydraulic cylinders and a specialised control system.

There are additional advantages. Since the diffuser structure no longer needs to allow for the return of the chain below the juice trays, supporting columns can be employed beneath the diffuser. The transverse steelwork beneath the diffuser screens, previously unsupported except at their ends, is supported at 3 m intervals in the chainless diffuser. Thus these components are no constraint to the width of diffusers.

The next possible limitation is the transverse beams that suspend the lifting screws. Since they are above the diffuser bed, they cannot be supported midway. With each lifting screw having a mass of around one tonne, the size of these beams becomes quite large. However, it is a simple problem of structural engineering and, in the 15 m wide chainless diffusers, they consist of plate girders 1.45 m deep. Similarly, the dewatering drum and the discharge kicker need to span the entire width of the diffuser, supported only on the bearings 15.9 m apart. Again, these are relatively simple engineering designs.

In trying to determine the maximum practical width of the diffuser, the final consideration is the feed into the diffuser. It is generally accepted that the bed of cane in a diffuser must be as level as possible in both directions. To achieve a level bed across the width of a 6 or 9 m diffuser may be relatively easy, but what is the practical limitation? The 12 m diffusers at Felixton use scraper conveyors to feed the prepared cane into the diffuser. These conveyors rake the top of the bed and ensure that it is perfectly flat, and the excess cane is returned to the infeed end through a system of conveyors. This concept is also generally used in Brazil. The drawbacks are that these scraper conveyors absorb more power; require additional installed conveyors to return the excess cane; and reduce the ability of operators to easily vary bed depth in the diffuser.
All the more recent diffuser designs, however, use conventional infeed carriers with one of two arrangements. Either the carrier is oriented at an angle to the back plate of the diffuser, or it has adjustable mitre floor plates. In this latter design, which is used in the chainless diffuser, as long as the cane supply into the infeed carrier is evenly distributed over its entire width, the design inherently allows for an even spread across the width of the diffuser. Of course, the wider diffusers require a wider infeed carrier so that the angle of the mitre can be maintained, and a 2.4 m wide infeed carrier for up to 15 m wide diffusers has been selected.

Given that the conventional constraints have been removed and that the possible constraints mentioned above are manageable through diligent engineering, Bosch Projects decided to develop a design for diffusers 15 m wide.

**Expandability of the chainless diffuser**

As mentioned earlier in this paper, one of the reasons given for the slow adoption of diffusers in other cane sugar industries is that a diffuser cannot have its capacity easily expanded. The alternatives are to build a second diffuser to process additional cane or to process the additional cane through the same diffuser at a reduced rate of extraction.

Since the chainless diffuser consists of 750 mm wide modules that move independently, it is a relatively simple exercise to add more modules. What is required is to:

- Extend the transverse structural steel beams below the moving floor, adding additional supports if necessary.
- Extend the juice trays. The juice trays of the chainless diffuser are based on the arc of a cylinder and are easy to extend.
- Extend the lifting screw beams.
- Move one side wall to its new position.
- Add more screen modules.

The probable expansion of diffusers is assumed during the design stage, unless a client specifically declines this option. To accommodate the future expansion, all of the components listed above are provided with bolted connections on the side of the diffuser that will be extended in future.

**Operating results of existing installations**

At the time of writing, two chainless diffusers are in operation. The first installation was a retrofit of a BMA diffuser at the UCL factory in South Africa in 2006 (Schröder et al., 2007) which has since completed 3 seasons of operation.

The second is the 500 tch diffuser constructed by Dedini at Usina Noroeste Paulista in Brazil which was commissioned in September 2008. Since the latter has been in operation for less than 12 months, there has been insufficient time elapsed for an objective evaluation of the performance of the diffuser. However, some aspects of the performance of the UCL diffuser can be regarded as representative.

The first season of operation at UCL was carefully documented by Schröder et al. (2007) and shortcomings in the original design were identified. Many of these were addressed after the first season, and the regular maintenance costs for the subsequent two seasons may be considered.

**Hydraulic systems maintenance**

The reciprocating diffuser screens are driven by two hydraulic systems, one at the feed end of the diffuser and one at the discharge end. The cost of maintenance of these systems has been recorded. The maintenance consisted of parts replacement and repairs (e.g. filters, seals, hoses and fittings) and the inspection of the condition of the systems during the off-crop; and a service contract with a service provider for a 2-weekly inspection of the systems during the crop period. The maintenance costs were as shown in Table 1.
Table 1—Hydraulic systems maintenance costs of the UCL diffuser: 2007–2008 ($).

<table>
<thead>
<tr>
<th></th>
<th>2007</th>
<th>2008</th>
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</thead>
<tbody>
<tr>
<td>Maintenance cost</td>
<td>44 875</td>
<td>37 868</td>
</tr>
<tr>
<td>Service contract</td>
<td>6 750</td>
<td>6 750</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>51 625</td>
<td>44 618</td>
</tr>
</tbody>
</table>

Wear strips maintenance

The reciprocating diffuser screens are supported on wear strips manufactured from a synthetic polymer material which has low friction co-efficient properties as well as withstanding the elevated diffuser temperatures. The average rate of wear of the thickness of these strips per season has been measured at 1 mm (out of a total useable thickness of approximately 14 mm). During the past three seasons, no wear strip replacements have been carried out due to excessive thinning.

Perforated screens maintenance

The perforated diffuser screens reciprocate with a stroke length of 1 metre. On the forward stroke, there is no relative movement between the diffuser screens and the sugarcane. However, when a diffuser screen retracts, it slides underneath the sugarcane bed and some wear of the perforated screen plates may be anticipated. During the past 3 seasons of operation, no replacement due to wear of perforated screen plates has been required, and no thinning has been measured.

Diffusers in Brazil

With the modern trend toward energy-efficient factories and the sale of electricity, cane diffusion is becoming more popular in Brazil. In 2004, there were eight diffusers in an industry of 347 factories. By 2007, this number had grown to 22 out of 393 factories representing 14 new diffusers in 46 new factories (Oliverio, 2007). The few diffusers in Brazil up to that time were mostly of the stationary screen type manufactured by Sermatec, including four with rated capacities of 12 000 t cane/d. However, the trend in Brazil is for larger units of operation which can process four million or more tonnes of cane per season, preferably in a single preparation/extraction line. Suppliers of mills claim capacities of up to 1250 t cane/h, but investors are aware of the disadvantages of milling tandems – higher power consumption, capital and maintenance costs, and the logistical challenges of getting mill spares from industrial centres located far from their estate operations. In light of this, there is a demand in Brazil for diffusers with capacities approaching those claimed for mills.

The Brazilian cane crop is forecast to grow from 562 million tonnes in 2008/09 to 829 million tonnes in 2015/16. This presents an interesting opportunity for diffuser suppliers who can overcome the size constraints of conventional diffusers.

The first chainless diffuser commissioned in Brazil is 12 m in width, the equivalent to the largest diffusers installed anywhere. It is located at Usina Noroeste Paulista in the state of Sao Paulo, and is designed to process 500 t/h (65 tonnes fibre per hour) and achieve 98% extraction. It is expandable to 625 t/h, or 15 m wide. This diffuser was commissioned in September 2008. Table 2 lists the chainless diffusers currently under construction Brazil.

Table 2—Chainless diffusers currently under construction.

<table>
<thead>
<tr>
<th>Factory</th>
<th>Design capacity (t/d)</th>
<th>Design capacity (t/h)</th>
<th>Future capacity (t/d)</th>
<th>Commissioning date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monte Verde</td>
<td>8 000</td>
<td>333</td>
<td>12 000</td>
<td>August 2009</td>
</tr>
<tr>
<td>Cosan Jatai</td>
<td>17 000</td>
<td>708</td>
<td>21 000</td>
<td>September 2009</td>
</tr>
<tr>
<td>Cabrera</td>
<td>12 000</td>
<td>500</td>
<td>15 000</td>
<td>October 2009</td>
</tr>
<tr>
<td>Brenco Morro Vermelho</td>
<td>15 000</td>
<td>625</td>
<td>16 500</td>
<td>November 2009</td>
</tr>
<tr>
<td>Brenco Alto Taquari</td>
<td>15 000</td>
<td>625</td>
<td>16 500</td>
<td>April 2010</td>
</tr>
<tr>
<td>Brenco Perolandia</td>
<td>15 000</td>
<td>625</td>
<td>16 500</td>
<td>April 2010</td>
</tr>
<tr>
<td>Brenco Agua Emendada</td>
<td>15 000</td>
<td>625</td>
<td>16 500</td>
<td>April 2010</td>
</tr>
<tr>
<td>Meridiano</td>
<td>16 500</td>
<td>688</td>
<td>21 000</td>
<td>June 2010</td>
</tr>
</tbody>
</table>
In considering the list, the following points are relevant:

- The first diffuser was commissioned very successfully in September 2008.
- The first of the 15 m diffusers will be commissioned in September 2009. This will provide immediate answers to the question of cane distribution over the width of a 15 m diffuser.
- Cosan is the largest sugarcane processor in Brazil, with 18 current factories which processed 44 million tonnes of cane in 2008/09. The Jatai factory, in the state of Goias, plans to process four million tonnes per annum.
- Brenco is a biofuels company newly established in Brazil. Ultimately they aim to establish 14 identical cane-to-ethanol plants.
- The diffusers for Cosan and Meridiano are special cases. Although perfectly sized for their initial duties, these diffusers will be expected to process cane at a rate of 875 tonnes per hour in the future at reduced rates of extraction. The diffusers will operate with a design bed level of 1.6 m and a speed of 0.92 m/min, giving a retention time of 65 minutes. The extraction is expected to be 96.5–97%.

In addition to this list, Mozambique Principle Energy Ltda has commissioned the design of a 440 t/h chainless diffuser for their Dombe Ethanol and Co-Generation plant. This diffuser will have the largest rated capacity in the Southern African region.

Conclusions

The development of diffusers in the cane sugar industry accelerated during the 1960s and 1970s, and diffusion is now the accepted technology in South Africa. The fact that diffusers are less well accepted elsewhere in the cane sugar world is possibly attributable to the ability of South African sugar technologists and engineers to overcome the problems initially associated with diffusion, whereas those elsewhere were less successful. The improvements made to the technology in South Africa have become universally accepted. However, the fundamental principles of cane transport through diffusers remained largely unchanged, until the chainless diffuser was developed in 2006. Since then, the chainless diffuser has been successfully sold into the Brazilian cane industry, where it meets the industry’s requirements of high capacity and low capital and maintenance costs and low power consumption. It is anticipated that, in trying to meet the demand for ever-increasing capacities, diffusers larger than 15 m wide will be developed within the next few years.

It appears that technological innovations from South Africa are as relevant to the world sugar industry as ever.

REFERENCES


LA MISE EN ŒUVRE DE LA TECHNOLOGIE SUCRIERE SUD AFRICAINE: LES PLUS GRANDS DIFFUSEURS DE CANNE A SUCRE DU MONDE

Par

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MOTS-CLEFS: Diffuseurs, Extraction, Brésil, Technologie, Sans Chaîne, Afrique Du Sud.

Résumé
LA DIFFUSION s’est établie en Afrique du Sud à partir de 1960 et 1970, à l'aide de la technologie européenne. La recherche locale et l'expérience ont permis le développement de diffuseurs conçus localement et l'industrie sud-africaine a atteint des taux d'extraction les plus élevés dans le monde. Les plus gros diffuseurs de l’industrie sud-africaine ont été installés à Felixton 2 en 1984, mesurant 12 mètres de large et capable de traiter au moins 350 t/h. En 2006, le premier changement réel des principes fondamentaux de conception a été introduit par Bosch Projects grâce au concept de 'Diffuseur sans chaîne'. Des neuf diffuseurs sans chaîne a être installé au Brésil entre 2008 et 2010, deux ont une taille similaire à ceux de Felixton et six sont plus grands. Le premier diffuseur de 12 mètres (à UNP avec une capacité de 500 t/h) est entre en service en septembre 2008. Les diffuseurs à Brenco, Cosan Jatai et Meridiano sont de 15 mètres de largeur, peuvent atteindre une extraction de 98 % à 625 t/h et seront les plus gros diffuseurs de canne à sucre du monde. Les diffuseurs de Cosan et Meridiano traiteront finalement 875 t/h. La vente de diffuseurs sans chaîne au Brésil est la preuve que la technologie sucrière sud-africaine continue à jouer un rôle de premier plan, même dans le secteur le plus compétitif d'une industrie mondiale, aux changements rapides.

LA IMPLEMENTACIÓN DE TECNOLOGÍA AZUCARERA SURAFRICANA: LOS DIFUSORES PARA CAÑA MAS GRANDES DEL MUNDO

Por

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PALABRAS CLAVE: Difusores, Extracción, Brasil, Tecnología, Sudáfrica.

Resumen
LA DIFUSION de caña ganó popularidad en Sudáfrica en las décadas de 1960 y 1970 usando tecnología europea. Investigación y desarrollos locales llevaron a difusores diseñados localmente y la industria sudafricana alcanzó los niveles de extracción más altos del mundo. Los difusores más grandes fueron instalados en Felixton 2 en 1984 con 12 metros de ancho y tasados conservativamente en 350 t/h. El primer cambio real a los fundamentos del diseño de difusores tuvo lugar cuando Bosch Projects introdujo el concepto del difusor sin cadena (‘Chainless Diffuser’ ) en 2006. De nueve difusores sin cadena a ser instalados en Brasil entre 2008 y 2010 dos son similares en tamaño a los de Felixton y seis son mayores. El primero de los difusores de 12 metros ( en UNP con capacidad nominal de 500t/h) fue puesto en operación en Septiembre 2008. Los difusores de Brenco, Cosan Jatai y Meridiano son de 15 metros de ancho diseñados para 98% de extracción a 625 t/h y serán los difusores mas grandes de caña en el mundo. Los difusores de Cosan y Meridiano finalmente procesarán 875 t/h. Las exitosas ventas del difusor sin cadenas en Brasil son evidencia que la tecnología azucarera y la ingeniería sudafricanas continúan jugando un papel de liderazgo aun en el sector más competitivo de una industria que cambia rápidamente.
HYDRAULIC MOTOR OF HIGH TORQUE
WITH CYLINDERS AND CRANKSHAFT

By

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KEYWORDS: Hydraulic Motor, High Torque Motor,
Multi Cylinder Motor.

Abstract
THE PAPER describes a new design of hydraulic motor for high torque and low speed applications. This design involves no speed reduction between the motor and the driven equipment. The motor is simple to manufacture as it uses components of common technology, with low cost and little complexity. It consists essentially of three double effect hydraulic cylinders and a rotary flow valve, all supported on a frame. It has the patented novelty that the three hydraulic cylinders carry out useful work in both directions, giving it a higher torque/mass density. A prototype motor has operated during one season in Havana Libre Sugar Mill of Cuba, with very promising results. The design of a new more robust model, promising better performance than the experimental prototype, is also presented.

Introduction
In the late 1970s, the Swedish company ‘Hägglunds’ introduced their High Torque, Low Speed (HTLS) hydraulic motors into Cuba (Per-Owe, 1981). The motors did not require any speed reduction between the motor and driven equipment. These motors have been used in the sugar industry in applications such as sugar crystallisers, cane conveyors, winches, mills crushing trash, big lathes and cane mills.

The main advantages of these motors were reported by Arias-Polo (2008b), Lewinski (2002a), Lewinski (2002b), Lewinski (2006) and Ljung (2006):

a) Direct coupling of drive to equipment without speed reduction.
b) Low assembly costs. Foundation is not needed.
c) Decrease of power loss in transmission.
d) Decrease of the required space. High torque/mass density
e) Wide speed range without gear ratio change.
f) Full torque at zero speed for indefinite time.
g) Can cope with frequent starts and stops.
h) Energy saving since power is not consumed unless required.
i) Low inertia (1% of conventional drive). The over loads and impact loads are controlled by a simple relief valve.
j) Long life, high technical reliability and low maintenance.
k) Reverse direction simple way achieved.

In several applications such as cane conveyors, pumps and fans, the working load has significant variability during its duty cycle. HLTS motors have advantages in these applications to achieve a considerable energy saving and softness in operation as described by Lewinski (2006) and Ljung (2006). These advantages are achieved by means of an automatic closed loop that controls the speed irrespective of the load. The low inertia mentioned above allows faster automatic control
than other alternatives that use mechanical speed reduction steps. When frequent stopping and starting are required, particularly in combination with high loads, hydraulic drives are the most suitable. These advantages of hydraulic drives have been demonstrated by Hägglunds in Cuba over more than 28 sugar harvest seasons.

Financial difficulties in the sugar industry have limited the further uptake of this valuable technology. With the objective of finding an economically viable and technically feasible alternative to existing HLTS motors, the author developed a novel hydraulic motor of high torque and low speed that is presented in this paper.

**Background to the invention**

The author carried out a literature search to look for solutions that met the objective of an economically viable and technically feasible alternative to existing HLTS hydraulic motors. One partial solution was identified, consisting of a two cylinder hydraulic motor applied to vertical crystallisers as described by Cameco Industries (1997), DDS Crystalliser (1995) and Groupe Fives-Lille (2002). From these references and the well-known classical steam engines, the author has improved the basic layout by using an odd number of cylinders to smooth the delivered power to the driven equipment.

Additionally, to increase the reliability of the new invention and its compactness, the author investigated the use of flow directional rotary valves that are widely used by companies such as Ebara Man. Co. (1998), Kawasaki Hydraulic Products (1999) and SAI s.p.a. (2004), and adapted this technology to the new design. This adaptation, to allow the cylinders to produce useful work in both directions, is not widely known.

**Description of invention**

This new hydraulic motor design has been patented (Arias-Polo, 2006). The design concept is shown in Figure 1.

![Fig. 1—Simplified drawing of the invention.](image)

The invention is a three cylinder hydraulic motor with a common point of action of forces 5. The hydraulic fluid, supplied by a pump, enters the directional rotary valve 1 at entrance E. This rotary valve 1 moves together with the crank 6, controlling the flow of fluid to the three cylinders 3 and, consequently, the sequence of operation and synchronisation of the cylinders. The fluid enters and leaves the cylinders through the lines 2. The stroke of the cylinders is transferred into rotational motion through the connecting rods 4. The ends of connecting rods are articulated in 8 and 5,
causing the rotation of the crankshaft 6, rotating the driver shaft 7 where useful torque is applied to the driven equipment with the angular speed $\theta$. The return of hydraulic fluid to the oil tank is also controlled through the rotary valve 1 through the exit S.

The patented technological novelty of this invention is that cylinders carry out useful work in both directions of their stroke. This feature enables the invention to achieve a higher torque to mass ratio compared to similar motors, with the additional advantages of smaller size, weight and cost.

**Experimental development under industrial conditions**

Based on the design presented by Arias-Polo (1998), a prototype was built by TANACEN in Cuba, a manufacturing plant belonging to the Cuban sugar industry. The prototype was installed in Havana Libre mill in Cuba, on a Blanchard Crystalliser of 34 m$^3$ rotating at a speed of up to 2 rpm (Figure 2), with promising results (Table 1). The equipment processed C massecuite successfully at different speeds (0.5, 0.75, 1.0 and 2.0 rpm), having to stop, after more than 300 operating hours, because of the end of the harvest season.

![Prototype operating under industrial conditions.](image)

**Table 1—Main experimental data.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor Displacement</td>
<td>$D_m$</td>
<td>43.8</td>
<td>L/rev.</td>
</tr>
<tr>
<td>Available motor torque</td>
<td>$T_d$</td>
<td>50 325.0</td>
<td>N·m</td>
</tr>
<tr>
<td>True motor torque</td>
<td>$T_e$</td>
<td>22 519.0</td>
<td>N·m</td>
</tr>
<tr>
<td>Maximal motor speed</td>
<td>$n_m$</td>
<td>2.0</td>
<td>rpm</td>
</tr>
<tr>
<td>Torque motor used</td>
<td>$U$</td>
<td>44.7</td>
<td>%</td>
</tr>
<tr>
<td>Brake motor power</td>
<td>$N_e$</td>
<td>4.7</td>
<td>kW</td>
</tr>
<tr>
<td>Pressure motor entrance</td>
<td>$P_1$</td>
<td>30.5</td>
<td>bar</td>
</tr>
<tr>
<td>Pressure motor outlet</td>
<td>$P_2$</td>
<td>7.0</td>
<td>bar</td>
</tr>
<tr>
<td>Flow to the motor</td>
<td>$Q$</td>
<td>133.6</td>
<td>L/min</td>
</tr>
</tbody>
</table>

**Design improvement**

After the operational experiences of the first prototype, the author developed a new design (Arias-Polo, 2002), to increase robustness and to achieve the maximum possible torque within the same motor casing). The diameter of the pistons and connecting rods, the driver shaft and the diameter of the shaft at the end of the three connecting rods were the most important parts updated.
The new design also incorporated a shrink disc coupling that doesn't require keys or splines, allowing quicker assembly and higher strength.

A full mathematical model and the corresponding software for the motor design and performance were described by Arias-Polo (2008a). Applying the model to the new design, new design parameters were obtained. A graph of available motor torque $T_1(\theta)$ vs. $\theta$ (rotation angle in radians) is presented in Figure 3. The average value $V_M$ is also shown. Table 2 shows the design specifications, based on the minimum torque shown in Figure 3.

![Graph showing available torque vs. rotation angle](image)

**Fig. 3—Torque available from improved design.**

<table>
<thead>
<tr>
<th>Pressure</th>
<th>300.0 [bar]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torque efficiency</td>
<td>97.0 [%]</td>
</tr>
<tr>
<td>Torque available</td>
<td>180 000.0 [N·m]</td>
</tr>
<tr>
<td>Specific Torque</td>
<td>600.0 [N·m/bar]</td>
</tr>
<tr>
<td>Mass</td>
<td>1360.0 [kg]</td>
</tr>
</tbody>
</table>

**Table 2—Data for the new design.**

Comparison of new design with current market leaders

From Hägglunds motor data, as presented by Hägglunds Drives (2002) and Lewinski (2002b), the author built performance curves, like that shown in the Figure 3, for four motor models.

A summary of the results, compared to the new design is presented in Table 3. Figure 4 shows the torque vs mass relationship. Interpolating the relationship for the Hägglunds motors, one can observe that the new design weighs about 30% less (1360 kg) than a Hägglunds motor design matching the torque of the new design (1975 kg).
Table 3—Comparison of new design with motors from market leader.

<table>
<thead>
<tr>
<th>Motor type</th>
<th>Torque maximum [N·m/bar]</th>
<th>Pressure maximum [bar]</th>
<th>Torque maximum [N·m]</th>
<th>Mass [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>MB 283</td>
<td>283</td>
<td>350</td>
<td>99 050</td>
<td>1395</td>
</tr>
<tr>
<td>MB 400</td>
<td>400</td>
<td>350</td>
<td>140 000</td>
<td>1625</td>
</tr>
<tr>
<td>MB 566</td>
<td>566</td>
<td>350</td>
<td>198 100</td>
<td>2108</td>
</tr>
<tr>
<td>MB 800</td>
<td>800</td>
<td>350</td>
<td>280 000</td>
<td>2580</td>
</tr>
<tr>
<td>New Design</td>
<td>600</td>
<td>300</td>
<td>180 000</td>
<td>1360</td>
</tr>
</tbody>
</table>

Further improving the available torque

The available torque can be increased by reducing the torque fluctuations through a revolution of the shaft, such as shown in Figure 3. To achieve this objective, an increase in the number of pistons is proposed, using two motors applied to the driven equipment, with different phases, as shown in Figure 5. Figure 6 shows the resulting performance.

Fig. 4—Comparison between the new design and the leader in market.

Fig. 5—Two motors applied in each extreme.
The available torque for two motors (the minimum value in Figure 6) with 95% torque efficiency is $T = 445\,880$ N·m. The torque for each motor is now $T/2 = 222\,940$ N·m, 23.85% higher than the 180 000 N·m shown in Table 2.

**Conclusions**

A new design of High Torque Low Speed hydraulic motor has been developed, with the patented novelty that cylinders carry out useful work in both directions of their stroke. That performance enables the invention to achieve a higher torque to mass ratio than existing motor designs, with the additional advantages of reduced size, weight and cost.

A prototype design was tested under industrial conditions in the Havana Libre Mill in the Republic of Cuba.

With the acquired experience, a new design was developed that modelling has shown has a mass that is less than 70% that of similar motors in the market.

In order to improve the torque to mass ratio further, a configuration is offered by increasing the number of pistons using two motors, with different phases. In this configuration, the torque for each motor will be 23.85% higher than when only one motor is used.

The simple mechanical construction allows the motor to be manufactured in a shop belonging to the Cuban Sugar Industry.

**REFERENCES**


Lewinski, J. (2002b). Nuevos Desarrollos de Mandos Hidráulicos de Molinos en la Industria Azucarera. Documentos publicados por Hägglunds Drives AB.


MOTRE HYDRAULIQUE DE COUPLE ELEVE
AVEC CYLINDRES ET ARBRE

Par

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MOTS CLEFS: Moteur Hydraulique,
Couple Élevé, Cylindres Multiples.

Résume
ON PRÉSENTE un moteur hydraulique d’une nouvelle conception; le moteur donne un couple élevé et des vitesses réduites. Il n’est pas nécessaire de réduire la vitesse entre le moteur et l’appareil qu’il conduit. La construction du moteur et sa technologie sont simples ; les coûts sont réduits. Le moteur comprend trois cylindres hydrauliques a effet double avec une vanne rotative, le tout bâti sur un châssis. Les trois cylindres hydrauliques travaillent dans deux directions, une idée nouvelle qui a été brevetée; cela permet un rapport couple/densité plus fort. Un moteur prototype a opère pendant une campagne a la sucrerie Havana Libre Sugar Mill de Cuba ; les résultats ont été très bons. Le papier donne aussi des détails sur un model plus robuste, promettant une performance supérieure comparée a celle du moteur prototype.
MOTOR HIDRÁULICO DE ALTO TORQUE
CON CILINDROS Y CIGUEÑAL

Por

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Resumen
EL ARTÍCULO describe un nuevo diseño de motor hidráulico para las aplicaciones de alto torque y baja velocidad de rotación. Estos diseños no necesitan reducción de velocidad entre el motor y el equipo a mover. El motor es simple de construir y utiliza componentes de tecnología común, con bajo costo y pequeña complejidad. Consiste esencialmente en tres cilindros hidráulicos de doble efecto y una válvula de flujo rotatoria, todo soportado por un bastidor. Tiene la novedad patentada que los tres cilindros hidráulicos realizan trabajo útil en ambas direcciones de la carrera, resultando una superior densidad de torque/masa. Un prototipo de este motor ha operado durante una Zafra en el ingenio Habana Libre de Cuba, con resultados muy prometedores. También se presenta el diseño de un nuevo modelo más robusto, el que promete mucho mejor desempeño que el prototipo experimental.
COMPARISON OF DIFFUSION AND MILLING
AT A CANE SUGAR PLANT

By

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KEYWORDS: Diffusion, Energy Efficient Extraction, Low Operation and Maintenance Cost, Exportable Electricity.

Abstract

With the advent of the diffusion technology and its improvement, diffusers have replaced mills for juice extraction at a few cane sugar plants due to their better extraction efficiency, lower manpower needs, lower power consumption, low operating and maintenance cost, increase in exportable electricity, and better operation flexibility. The performance of a cane diffuser at The Andhra Sugars Limited, Sugar Unit – II at Taduvai has been elucidated and a comparison done between diffusion and milling. Taduvai achieves a reduced milling extraction (RME)\(^1\) of 98.4% and pol in bagasse (%) of 0.84 and has 51% lower manpower, 18% lower power consumption and 60% lower operation and maintenance costs compared to a milling tandem. The vacuum filter station has been eliminated. With a cane diffuser, 2616 kW more electricity can be exported than with a milling tandem.

Introduction

‘In the sugar factory, diffusion is therefore the phenomenon by which the cells of the beet or the cane, immersed in water or a solution of lower concentration than the juice which they contain, give up to that water or to that solution a part or all of the sugar forming the excess of concentration of their juices’, quoted Hugot (1986).

In diffusion, sugar extraction from cane is effected by rupturing the cane cells and then washing the ruptured cells with water or juice. So it is necessary that the preparatory index of around 90% be achieved to obtain a RME of 98% or higher. This process of extraction of sugar from cane offers several advantages over milling.

Percolation type diffusers are widely used in the cane sugar industry. There are two types of percolation diffusers in use – the fixed screen and the moving screen.

The cane sugar industry has used milling for juice extraction. With the advent of diffusion technology and its improvement, this process has replaced mills at the juice extraction station in a few cane sugar plants; particularly due to its better extraction efficiency, lower manpower needs, lower power consumption, lower operating and maintenance costs, increase in exportable electricity and better operating flexibility.

In 1969, a moving screen percolation type bagasse diffuser was installed at The Andhra Sugars Limited, Sugar Unit – I, at Tanuku in Southern India. Satisfied with its performance, a second moving screen percolation type bagasse diffuser was installed in 1977 and a moving screen percolation type cane diffuser was installed in 1997 at Sugar Unit – II at Taduvai.

This is the only cane sugar company with diffusers, producing direct consumption plantation white sugar of around 30 IU colour. All information presented in this paper is from the Taduvai plant (see Table 1).

---

\(^1\) Reduced to common basis of 12.5% fibre on cane; details in Annex 2
Table 1—Test results of direct white plantation sugar produced at Taduvai.

<table>
<thead>
<tr>
<th>Grade – Grain size</th>
<th>Colour(^2) IU</th>
<th>Ash %</th>
<th>Turbidity IU</th>
<th>SO(_2) ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-31 &gt; 600 Microns</td>
<td>30</td>
<td>0.028</td>
<td>23</td>
<td>10.56</td>
</tr>
<tr>
<td>M-31 &gt; 1180 Microns</td>
<td>34</td>
<td>0.025</td>
<td>20</td>
<td>10.24</td>
</tr>
</tbody>
</table>

Cane diffusion

Cane is prepared by a fiberiser or a shredder to a preparatory index of 90% or higher and passed through the diffuser with no mills before the diffuser and only one dewatering mill after the diffuser; see Figure 1.

Initially diffusers at most cane sugar plants were bagasse diffusers, where the existing mills were used as primary and dewatering mills.

With the advent of improved fiberisers and shredders that achieve 90% and higher preparatory index, cane diffusion became popular, doing away with the primary mill, resulting in multiple savings as mentioned in the abstract and introduction.

![Fig. 1—A diffuser.](image)

There are a few aspects to be borne in mind when considering the use of diffusion at a cane sugar plant:

- Compared to milling, diffusion requires 2 to 3% more low pressure steam, to heat the prepared cane to the operating temperature of 80°C, using vapour bled from the 2\(^{nd}\) effect evaporator. This extra 3% steam is first used to generate electricity and then used to heat the prepared cane.
- Imbibition of 45% on cane is given at the diffuser, requiring slightly more evaporator capacity.
- Experience shows that addition of the clarifier underflow (mud) into the diffuser made a minor difference in quantity of ash or on the calorific value of the bagasse.

\(^2\) ICUMSA Method GS2/3-10
Operation of a cane diffuser at the Taduvai Sugar Plant

The cane diffusion process has three major operations:

Cane preparation

A heavy duty swing hammer type horizontal fiberiser with 144 hammers (each weighing 17.5 kg) driven by a 1865 kW steam turbine is being used at Taduvai. An auto-feed arrangement is used to have a uniform bagasse mat feeding the diffuser. The power consumed for cane preparation is 1790 kW though 2242 kW is installed.

Juice extraction

Juice extraction is by a moving screen, percolation type cane diffuser of 5000 t/d capacity. It is like a long rail box wagon, with its bottom having a horizontally moving screen running the full length of the diffuser. Below the moving screen are 15 recirculation trays, 2 scalding juice tanks and 1 draft juice tank. At the top, fixed just below the roof of the diffuser are 15 distributors located throughout the length of the diffuser at the centre of the recirculation trays. The screen moves slowly from the feed to the discharge end, carrying a bagasse mat of uniform thickness. Imbibition at 45% on cane is added on to this mat at the discharge end of the diffuser. Press juice is added on to the mat at the second last compartment from the discharge end of the diffuser. This press juice is heated from 60 to 85°C, using 3rd vapour in a direct contact heater.

Pumps at the recirculation trays pump the percolated liquid through the distributor above the preceding tray. The liquid percolates through the bagasse mat and collects in the recirculation trays below. The liquid moves from the discharge end to the feed end of the diffuser gradually increasing its concentration by taking up the soluble matter, resulting in a counter current extraction. It takes 60 minutes for the bagasse mat to traverse the length of the diffuser, while the liquid takes 20 minutes. The juice goes to the process house, with the flow being controlled by the level of the juice in the scalding juice tank. The juice from the diffuser passes through a screen before being sent to the process house. This quantity is around 110 to 115% on cane.

At the discharge end of the diffuser, the bagasse drops on to a rake carrier, which transports it to the dewatering mill. To avoid blocking of the bagasse mat by fine particles, 2 sets of lifting screws are provided, one after the feed end and the other before the discharge end of the diffuser, facilitating proper drainage of the liquid.

The liquid distribution system automatically adjusts (Rein et al., 1992) by sensing the liquid level in the bed using a differential pressure transmitter through a DCS (distributed control system) to have better percolation of liquid through the bagasse mat. With this arrangement, the point of application of the liquid moves forward or backward, adjusted by means of a pneumatic cylinder. The power used at the diffuser is 448 kW though 574 kW is installed. Table 2 shows the diffuser performance data.

To have a better extraction and to minimise microbial activity in the diffuser, the temperature inside the diffuser is maintained at around 80°C. To achieve this, a fully automated and controlled injection of 1st vapour is provided. To raise the temperature of the bagasse to the operating temperature, the juice from the scalding juice compartment is heated in two multi-pass vertical juice heaters and spread over the bagasse mat at the feed end of the diffuser.

At this stage, milk of lime is added to maintain the pH between 5.8 and 6.0. As the temperature of the juice in the diffuser is maintained at around 80°C, inversion is minimal. Figure 2 shows the concentration (°Brix), pH, temperature (°C) and reducing sugar (RS) per 100°Brix of the juice at the various compartments of the diffuser at Taduvai indicating that there is minimal inversion in the diffuser. The clarifier underflow (mud) is pumped into the diffuser near the first row of lifting screws, at a point of matching concentration, eliminating the vacuum filter station and the need for disposal of the filter cake. The mat of bagasse acts as a filter, removing the mud particles in the underflow (mud) of the clarifier and the suspended particles in the diffuser juice
Addition of the clarifier underflow (mud) into the diffuser has not negatively affected the boiler. It has in fact resulted in:

- Power saving of 112 kW.
- Increase in recovery by 0.06% on cane.
- Steam saving of 1%, as there is no cake washing.

Performance data for the diffuser at Taduvi are presented in Table 2.

<table>
<thead>
<tr>
<th>Table 2—Diffuser performance data at Taduvi.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cane processed (t/d)</strong></td>
</tr>
<tr>
<td><strong>Mill extraction (%)</strong></td>
</tr>
<tr>
<td><strong>Reduced mill extraction (%)</strong></td>
</tr>
<tr>
<td><strong>Recovery (% on cane)</strong></td>
</tr>
<tr>
<td><strong>Sugar (% on cane)</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Particulars/time</th>
<th>12:00–13:00</th>
<th>14:00–15:00</th>
<th>16:00–17:00</th>
<th>18:00–19:00</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Crushing rate (t/h)</strong></td>
<td>188</td>
<td>170</td>
<td>170</td>
<td>170</td>
</tr>
<tr>
<td><strong>Diffuser screen speed (m/min)</strong></td>
<td>0.744</td>
<td>0.744</td>
<td>0.744</td>
<td>0.744</td>
</tr>
<tr>
<td><strong>Diffuser mat thickness (mm)</strong></td>
<td>1600</td>
<td>1600</td>
<td>1600</td>
<td>1600</td>
</tr>
<tr>
<td><strong>Scalding juice No.1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow (m³/h)</td>
<td>170</td>
<td>174</td>
<td>172</td>
<td>170</td>
</tr>
<tr>
<td>Temp. (°C)</td>
<td>86</td>
<td>90</td>
<td>84</td>
<td>84</td>
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<tr>
<td><strong>Scalding juice No.2</strong></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Flow (m³/h)</td>
<td>173</td>
<td>175</td>
<td>176</td>
<td>175</td>
</tr>
<tr>
<td>Temp. (°C)</td>
<td>86</td>
<td>90</td>
<td>84</td>
<td>84</td>
</tr>
<tr>
<td><strong>Scalding juice</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concentration (°Brix)</td>
<td>13.98</td>
<td>14.42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pol (%)</td>
<td>11.54</td>
<td>12.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Purity (%)</td>
<td>82.55</td>
<td>83.22</td>
<td></td>
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<td><strong>Imbibition water</strong></td>
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<tr>
<td>Flow (m³/h)</td>
<td>78</td>
<td>79</td>
<td>76</td>
<td>77</td>
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<tr>
<td>Temp. (°C)</td>
<td>84</td>
<td>88</td>
<td>82</td>
<td>82</td>
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<tr>
<td><strong>Draft juice</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow (m³/h)</td>
<td>192</td>
<td>199</td>
<td>202</td>
<td>203</td>
</tr>
<tr>
<td>Temp. (°C)</td>
<td>64</td>
<td>68</td>
<td>72</td>
<td>70</td>
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<tr>
<td>Concentration (°Brix)</td>
<td>14.32</td>
<td>14.96</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pol (%)</td>
<td>11.88</td>
<td>12.50</td>
<td></td>
<td></td>
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<tr>
<td>Purity (%)</td>
<td>82.96</td>
<td>83.56</td>
<td></td>
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<tr>
<td><strong>Press juice</strong></td>
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<tr>
<td>Flow (m³/h)</td>
<td>137</td>
<td>136</td>
<td>124</td>
<td>137</td>
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<tr>
<td>Temp. (°C)</td>
<td>72</td>
<td>66</td>
<td>80</td>
<td>80</td>
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<tr>
<td>Concentration (°Brix)</td>
<td>1.64</td>
<td>1.36</td>
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<tr>
<td>Pol (%)</td>
<td>1.14</td>
<td>0.99</td>
<td></td>
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<tr>
<td>Purity (%)</td>
<td>69.51</td>
<td>72.79</td>
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<table>
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<th>Temp. of circulation juice (°C)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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<th>9</th>
<th>10</th>
<th>11</th>
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<th>13</th>
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<tbody>
<tr>
<td>Stage 1</td>
<td>82</td>
<td>83</td>
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<td></td>
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<tr>
<td>Stage 2</td>
<td>90</td>
<td>88</td>
<td>84</td>
<td>88</td>
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<tr>
<td>Stage 3</td>
<td>82</td>
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<td>86</td>
<td>84</td>
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<tr>
<td>Stage 4</td>
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<tr>
<td>Stage 5</td>
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<tr>
<td>Stage 6</td>
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<tr>
<td>Stage 7</td>
<td>87</td>
<td>86</td>
<td>86</td>
<td>87</td>
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<td>Stage 8</td>
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<td>Stage 9</td>
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<td>Stage 10</td>
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<td>Stage 11</td>
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<td>Stage 12</td>
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<td>86</td>
<td>86</td>
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<td></td>
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<tr>
<td>Stage 13</td>
<td>92</td>
<td>92</td>
<td>90</td>
<td>90</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Diffuser injection steam flow (t/h) | 4.57 |
| Steam to scalding juice heaters (t/h) | 5.22 |
| Diffuser outlet bagasse | Pol (%) | 1.05 | 1.04 |
|                         | Moist. (%) | 81.50 | 80.50 |
| Final bagasse           | Pol (%) | 0.89 | 0.79 |
|                         | Moist. (%) | 50.50 | 51.00 |
| Preparatory Index (%)   | 89.85 | 89.31 |
Fig. 2—Graph of concentration (°Brix), pH, Temperature and RS/100°Brix at various compartments of the cane diffuser at Taduvai.

**Dewatering of bagasse**

The moisture content of the bagasse discharged from the diffuser is around 80%. It passes through a 991 mm × 1982 mm mill with a TRPF (toothed roller pressure feeder). The moisture content of bagasse at the outlet of the dewatering mill is around 50.5%. This bagasse is passed through a flash dryer bringing the moisture down to 42%, thus improving the efficiency of the boiler. This has enabled each of the 40 t steam/h boilers to produce 5 t/h more steam. The power consumed at the dewatering mill is 507 kW, though 1082 kW is installed.

**Advantages of cane diffusion over milling** (5000 t/d capacity, and a 150 day season)

**Better extraction efficiency**

While the RME at many mills is about 96% and pol in bagasse (%) is about 2, at Taduvai the RME is around 98.4% and pol in bagasse (%) is 0.84, gaining 0.374 in recovery (% on cane), while elimination of the vacuum filter station contributes 0.06 (% on cane) to the recovery. The sugar so gained is approximately US$1.95 per tonne of cane processed. Recovery gains for diffusion and milling are presented in Table 3.

**Table 3**—Calculated recovery gain with a diffuser.

<table>
<thead>
<tr>
<th>Particulars</th>
<th>Diffusion (RME of 98.4%)</th>
<th>Milling (RME of 96%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pol in cane (%)</td>
<td>14.0</td>
<td>14.0</td>
</tr>
<tr>
<td>Pol in mixed juice (%) on cane</td>
<td>13.744</td>
<td>13.415</td>
</tr>
<tr>
<td>Pol in bagasse (%) on cane</td>
<td>0.256</td>
<td>0.585</td>
</tr>
<tr>
<td>Pol in filter cake (%) on cane</td>
<td>–</td>
<td>0.060</td>
</tr>
<tr>
<td>Filter cake (%) cane</td>
<td>–</td>
<td>2.30</td>
</tr>
<tr>
<td>Pol in Molasses (%) on cane</td>
<td>1.219</td>
<td>1.134</td>
</tr>
<tr>
<td>Molasses yield (%) on cane</td>
<td>4.3</td>
<td>4.0</td>
</tr>
<tr>
<td>Unknown losses (%) on cane</td>
<td>0.06</td>
<td>0.19</td>
</tr>
<tr>
<td>Pol yield (%) on cane</td>
<td>12.465</td>
<td>12.031</td>
</tr>
</tbody>
</table>
Sugar recovery at a cane diffusion plant is 0.434% points on cane higher than at a similar capacity milling plant.

**Lower manpower**

The manpower engaged at the extraction station at Taduvai and a comparative milling tandem is presented in Table 4.

<table>
<thead>
<tr>
<th>Description</th>
<th>Diffusion</th>
<th>Milling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manpower</td>
<td>21</td>
<td>43</td>
</tr>
</tbody>
</table>

**Lower power consumption**

The installed and consumed power (kW) at a diffuser and a milling tandem (4 sets of mills) is shown in Table 5.

<table>
<thead>
<tr>
<th>Description</th>
<th>Diffusion</th>
<th>Milling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane preparation</td>
<td>2242</td>
<td>1790</td>
</tr>
<tr>
<td></td>
<td>1839</td>
<td>1469</td>
</tr>
<tr>
<td>Juice extraction</td>
<td>1716</td>
<td>1165</td>
</tr>
<tr>
<td></td>
<td>2701</td>
<td>2145</td>
</tr>
<tr>
<td>Total power (kW)</td>
<td>3958</td>
<td>2955</td>
</tr>
<tr>
<td></td>
<td>4540</td>
<td>3614</td>
</tr>
</tbody>
</table>

There is a saving of 659 kW power with a diffuser. With the elimination of the vacuum filter station this saving increases to 749 kW. While a RME of 98% and higher is achieved with a diffuser, to achieve this RME with a milling tandem, two more sets of mills are needed, requiring an additional installed power of 1268 kW.

**Lower operation and maintenance costs**

The operation and maintenance cost at a diffuser and a milling tandem for a 150 day operation is shown in Table 6.

<table>
<thead>
<tr>
<th>Description</th>
<th>Diffusion</th>
<th>Milling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Out of 3 rollers, 1 unit reshellin/year</td>
<td>5130</td>
<td>20 520</td>
</tr>
<tr>
<td>For 1 trash plate @ $1500/piece</td>
<td>1500</td>
<td>6000</td>
</tr>
<tr>
<td>For mill rollers arcing @ $720 per mill</td>
<td>720</td>
<td>2880</td>
</tr>
<tr>
<td>Out of 2 mill scrapers, 1 unit per year @ $515/piece</td>
<td>515</td>
<td>2060</td>
</tr>
<tr>
<td>Out of 2 mill roller pinions 1 unit per year @ $310/piece (rebuilding only)</td>
<td>310</td>
<td>1240</td>
</tr>
<tr>
<td>For maintenance of 1 pumps @ $180/pump</td>
<td>180</td>
<td>900</td>
</tr>
<tr>
<td>For maintenance of 1 inter carriers @ $2488 for 4 years</td>
<td>226</td>
<td>2488</td>
</tr>
<tr>
<td>For maintenance of 8 mill bearings @ $620 for 6 years</td>
<td>826</td>
<td>3304</td>
</tr>
<tr>
<td>Spares for 1 prime mover and reduction gear @ $4500/piece</td>
<td>4500</td>
<td>18 000</td>
</tr>
<tr>
<td>Lubricants for mill bearings 12 litres/8h/mill @ $1.65 per litre.</td>
<td>8910</td>
<td>35 640</td>
</tr>
<tr>
<td>Lubricants for prime mover &amp; reduction gears 800 litres/8h/mill @ $2.80/litre, for one set of mill for 2 years</td>
<td>1120</td>
<td>4480</td>
</tr>
<tr>
<td>Other Lubricants</td>
<td>370</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>Labour cost for off-season overhauling of one set of mills 720 man-days @ $7.2/man-day</td>
<td>5184</td>
<td>20 736</td>
</tr>
<tr>
<td>Labour cost for overhauling of a diffuser 1260 man-days @ $7.2/man-day</td>
<td>9072</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>Spares and off-season maintenance for a diffuser: runner flats 2 t @ $1130 – 3 years life; main chain @ $50 × 244 links for 6 years life</td>
<td>2786</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>Spares for 6 lifting screws 4 years life @ $750</td>
<td>1500</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>Spares for 21 circulation and scalding pumps @ $130/pump</td>
<td>2790</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>Painting cost</td>
<td>1200</td>
<td>Painting cost</td>
</tr>
<tr>
<td>Total rounded off to:</td>
<td>47 500</td>
<td>Total rounded off to:</td>
</tr>
<tr>
<td></td>
<td>119 000</td>
<td></td>
</tr>
</tbody>
</table>
Lower Capital, Foundation and Construction Costs

The price of a diffuser and a milling tandem of 5,000 t/d capacity is shown in Table 7.

Table 7(a)—Capital cost.

<table>
<thead>
<tr>
<th>Currency</th>
<th>Diffusion</th>
<th>Milling</th>
</tr>
</thead>
<tbody>
<tr>
<td>US$</td>
<td>2990 000</td>
<td>3 958 000</td>
</tr>
</tbody>
</table>

The foundation and construction costs for a diffuser are much lower than for a milling tandem, as a diffuser can be installed outdoors while a milling tandem requires a complete roof cover.

Table 7(b)—Foundation and construction costs.

<table>
<thead>
<tr>
<th>Description</th>
<th>Diffusion</th>
<th>Milling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foundation cost for diffuser</td>
<td>12 320</td>
<td></td>
</tr>
<tr>
<td>Foundation cost for one dewatering mill</td>
<td>92 400</td>
<td></td>
</tr>
<tr>
<td>Cost of construction for dewatering mill building</td>
<td>118 000</td>
<td></td>
</tr>
<tr>
<td>Foundation cost for 4 sets of mills, 4 intermediate carriers and 4 pumps @ $92 400/set</td>
<td>369 600</td>
<td></td>
</tr>
<tr>
<td>Cost of construction for milling tandem building</td>
<td>295 700</td>
<td></td>
</tr>
<tr>
<td>Total cost</td>
<td>222 720</td>
<td>665 300</td>
</tr>
</tbody>
</table>

Clarification and filtration

The bagasse mat in a diffuser acts as a filter for the juice. The suspended solids in the draft juice from the diffuser are around 80 ppm, while it is about 2000 ppm with a milling tandem. With the addition of the clarifier underflow (mud) into the diffuser, the pol loss in the filter cake is ‘0’. ‘No’ recirculation of filtrate to draft juice results in lower suspended impurities in the draft juice, better floc formation and better clear juice transmittance, as seen in Figure 3.

Fig. 3—Colour of draft, sulphited and clarified juice at Taduvai.

There is a notion that as the diffuser draft juice is higher in colour, use of a diffuser is not conducive to produce direct white sugar. Figure 3 shows the juice colour achieved at the cane diffuser, while Table 1 and Annex 1 show the quality of sugar produced at Taduvai.
Lower unknown losses

As diffusion takes place in enclosed equipment, at a temperature of 80 to 85°C, microbial activity is minimal. In milling, extraction is done in the open, at ambient temperature, so most of the unknown loss is due to microbial activity, loosing eight parts of sucrose to one part of lactic acid, while it is only two parts of sucrose to one part of lactic acid in a diffuser (Mackrory et al., 1984).

Increase in Exportable electricity

A cane sugar plant with a boiler at 4.5 Mpa and 420°C and a diffuser would export about 2616 kW more electricity than with a milling tandem as seen in Table 8.

Table 8—Comparison of energy requirement.

<table>
<thead>
<tr>
<th>Description</th>
<th>Diffusion</th>
<th>Milling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane crushing rate (t/d)</td>
<td>5000</td>
<td>5000</td>
</tr>
<tr>
<td>Bagasse yield (% on cane)</td>
<td>30.50</td>
<td>29.28</td>
</tr>
<tr>
<td>Bagasse production (t/h)</td>
<td>70.15</td>
<td>67.34</td>
</tr>
<tr>
<td>Bagacillo used for filter cake (t/h) @ 3 (% on cane)</td>
<td>0.00</td>
<td>2.3</td>
</tr>
<tr>
<td>Bagasse available (t/h)</td>
<td>70.15</td>
<td>65.06</td>
</tr>
<tr>
<td>Exhaust steam (% on cane)</td>
<td>48</td>
<td>45</td>
</tr>
<tr>
<td>Exhaust steam requirement (t/h)</td>
<td>110.4</td>
<td>103.5</td>
</tr>
<tr>
<td>De-super heated water required (t/h)</td>
<td>3.62</td>
<td>3.39</td>
</tr>
<tr>
<td>High pressure steam required to produce the required exhaust (t/h)</td>
<td>106.78</td>
<td>100.11</td>
</tr>
<tr>
<td>HP steam required for miscellaneous uses (t/h) at 3.5(% on cane)</td>
<td>8.05</td>
<td>8.05</td>
</tr>
<tr>
<td>Total high pressure steam to be generated (t/h)</td>
<td>114.83</td>
<td>108.16</td>
</tr>
<tr>
<td>Power generated while producing the required exhaust (kW)</td>
<td>13 350</td>
<td>12 510</td>
</tr>
<tr>
<td>Power used for cane preparation (kW)</td>
<td>1790</td>
<td>1469</td>
</tr>
<tr>
<td>Power used for juice extraction (kW)</td>
<td>1165</td>
<td>2145</td>
</tr>
<tr>
<td>Power used for other plant load (kW)</td>
<td>4031</td>
<td>4216</td>
</tr>
<tr>
<td>Total power utilised (kW)</td>
<td>6986</td>
<td>7830</td>
</tr>
<tr>
<td>Surplus power (kW)</td>
<td>6364</td>
<td>4680</td>
</tr>
<tr>
<td>Bagasse consumed (t/h)</td>
<td>51.5</td>
<td>48.5</td>
</tr>
<tr>
<td>Surplus bagasse (t/h)</td>
<td>18.65</td>
<td>16.56</td>
</tr>
<tr>
<td>Steam equivalent to surplus bagasse (t/h)</td>
<td>41.58</td>
<td>36.92</td>
</tr>
<tr>
<td>Power generated from the surplus bagasse with a condensing turbine (kW)</td>
<td>8316</td>
<td>7384</td>
</tr>
<tr>
<td>Net exportable power (kW)</td>
<td>14 680</td>
<td>12 064</td>
</tr>
<tr>
<td>Additional exportable power (kW)</td>
<td>2616</td>
<td></td>
</tr>
</tbody>
</table>

Better operating flexibility

A diffuser can be operated from 20 to 100% of its rated capacity without significant loss in efficiency by merely varying the thickness of the bagasse mat and the screen speed.

Conclusion

Diffusion has a definite advantage over milling due to higher extraction, lower manpower needs, lower power consumption, lower operating and maintenance costs, increase in exportable electricity and better operating flexibility. For a cane sugar company considering setting up a new sugar plant, it would be advantageous in the interest of a better bottom line to use diffusion for juice extraction.

Acknowledgement

The Author thanks Dr M. Krishnamurthi, Dr Raoul Lionnet, Mr Dennis Walthew and Mr Serg Kong for reviewing the manuscript.

REFERENCES


Annex 1: Taduvai sugar compliance to EC-2 grade requirements.
Annex 2: Reduced (mill) extraction.

Recorded extraction reduced to a common basis of 12.5 % fiber in cane, Noel Deere

\[ E_{12.5} = \frac{(7-V)}{7} \times 100 \]

Where  
\[ V = \frac{(1 - e)(1 - f)}{f} \]

- \( E_{12.5} \): Reduced (mill) extraction (%)
- \( V \): Lost juice % fiber
- \( e \): Recorded (mill) extraction
- \( f \): Fiber % cane

### INSTITUT NEHRING

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polarization (ICUMSA)</td>
<td>100.0</td>
</tr>
<tr>
<td>Humidity (ICUMSA)</td>
<td>0.02</td>
</tr>
<tr>
<td>Invert sugar (ICUMSA)</td>
<td>0.03</td>
</tr>
<tr>
<td>Copper</td>
<td>not detectable (&lt; 0.07 mg/kg)</td>
</tr>
<tr>
<td>Lead</td>
<td>not detectable (&lt; 0.07 mg/kg)</td>
</tr>
<tr>
<td>Arsenic</td>
<td>not detectable (&lt; 0.07 mg/kg)</td>
</tr>
<tr>
<td>Turbidity</td>
<td>5</td>
</tr>
<tr>
<td>SO2 content</td>
<td>not detectable (&lt; 6 mg/kg)</td>
</tr>
<tr>
<td>Iron</td>
<td>1.7 mg/kg</td>
</tr>
</tbody>
</table>

Dr. Rainer Mogele
COMPARAISON DE LA DIFFUSION ET DES MOULINS DANS UNE SUCERIE

Par

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MOTS-CLEFS: Diffusion, Energie et Extraction, Coûts de l’Opération et de la Maintenance, Exportation d’électricité.

Résumé
AVEC l’avènement de la technologie de diffusion et de son amélioration, les diffuseurs ont remplacés les moulins pour l’extraction du jus dans des sucreries. Comparée aux moulins la diffusion donne une meilleure efficacité d’extraction, demande moins de main d’œuvre, et consomme moins d’énergie; les coûts de maintenance et de l’opération sont plus faibles. Elle permet aussi d’exporter plus d’électricité et donne une opération plus flexible. Les performances d’un diffuseur de canne à The Andhra Sugars Limited, Unit Sugar-II à Taduvai ont été éucidées et une comparaison effectuée entre la diffusion et les moulins. Taduvai réalise une extraction réduite (RME) de 98.4%, un pol % bagasse de 0.84, une maintenance réduite de 51%, une consommation d’énergie réduite de 18%, et 60% de réduction pour les coûts d’opération et d’entretien par rapport à un tandem. La station de filtre a été éliminée. Avec un diffuseur on a augmenté l’exportation de l’électricité par 2616 kW, compare aux moulins.

COMPARACIÓN ENTRE DIFUSIÓN Y MOLIENDA EN UNA PLANTA DE AZÚCAR DE CAÑA

Por

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PALABRAS CLAVE: Difusión, Energía, Extracción, Mantenimiento, Costos, Cogeneración.

Resumen
CON la aparición de la tecnología de difusión y su mejoramiento, los difusores han reemplazado los molinos para la extracción de jugo en algunas fábricas debido a su mejor eficiencia de extracción, menores requerimientos de mano de obra, menor consumo de energía, menores de operación y mantenimiento, incremento en cogeneración y mayor flexibilidad de operación. El desempeño del difusor en la Unidad II de Andhra Sugars Limited, en Taduvai ha sido evaluado y se comparado con la tecnología de molienda. Taduvai alcanza una extracción reducida de 98.4% y pol en bagazo (%) de 0.84 y tiene 51% menos mano de obra, 18% menos consumo de potencia, y costos de operación y mantenimiento 60% menores si se lo compara con un tren de molinos. La estación de filtración fue eliminada y con este difusor pueden exportarse 2616 Kw más que con un tándem de molinos.
FACTORY CONCEPTS FOR VERY LOW STEAM DEMAND
AND STATUS OF IMPLEMENTATION

By

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KEYWORDS: Co-generation, Steam Efficiency,
Energy Benchmarking.

Abstract

THE EXPORT of power from cane sugar factories allows the production of ‘green energy’
and proves nowadays as a substantial source of revenue as well. Looking to the co-
generation potential of the cane sugar industry, the power export is in fact still at a very
early stage. The report gives an overview about concepts and measures that are required
to achieve a low steam demand and high electrical power export for different factory
concepts. The impact of sugar extraction by mills and diffusers as well as the option of
producing refined sugar in an attached refinery is investigated. The factory models
investigated allow steam demands to reduce to the range of 26–34% steam on cane.
Such factory concepts are not theoretical any more but have been implemented and
successfully proven in several plants in India, Brazil and Pakistan in the last five years.
The report gives an overview about the actual achievements.

Introduction

While saving of process steam has not been very attractive for many cane mills in the past,
the situation has turned in the last decade substantially since electrical power can be sold for
reasonable prices, in many cane processing countries, to the national grid or directly to external end
consumers. The carbon credit trade has acted to some extent as a catalyst to accelerate this process
and has proven to be a most welcome add-on to boost the electrical power production of cane sugar
factories. Electrical power prices of 50–60 €/MWh in countries like Brazil and India make power
exports more attractive. The market price for each tonne of carbon dioxide substituted by the
production of electrical power from bagasse is approx. 5–15 €/t CO2 and this adds to the revenues.

Taking into account that, with well proven technologies, electrical power exports of 100–
125 kWh/t cane are already possible today, the potential to create ‘green energy’ is huge. In the case
where bagasse gasification is applied, even 200 kWh/t cane would be possible in the future (Turn,
1999). Considering sugarcane production in more than 100 countries worldwide with approx. 1800–
2000 sugarcane and bio-fuel (ethanol) factories processing approximately 1558 million t cane/year
(FAOSTAT, 2008), the power production potential amounts to 156–179 TWh/year. In other words,
20 MW power export capacity would have to be installed in each cane processing factory in order
to match the actual potential.

Another trend observed is producing better sugar qualities locally with a tendency to white
(refined) sugar production of less than 45 ICUMSA units in back-end refineries.

This report gives an overview about energy efficient process schemes employed in the cane
sugar industry and typical benchmark numbers that can be achieved.

Base concepts

There are various configurations possible to process sugarcane to sugar. Mill and diffuser
extraction concepts compete, with diffusers gaining more ground on an international basis today.
While in most countries a three-stage crystallisation scheme with an eventually attached back-end refinery is typical, in Brazil usually approximately half of the sucrose in cane is converted to sugar and half to ethanol. A diffuser and mill-based plant concept with and without back-end refinery have been chosen to benchmark the steam demand and the power export. Sub scenarios have been created in order to show, for example, the effect of different imbibition rates. In Table 1 the main input variables for the subsequent calculations are summarised.

Table 1—Base data for the process calculations.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane crushing rate</td>
<td>10,000 t cane/day</td>
</tr>
<tr>
<td>Effective crop length</td>
<td>180 days</td>
</tr>
<tr>
<td>Sugar content in cane</td>
<td>14%</td>
</tr>
<tr>
<td>Fibre content in cane</td>
<td>14%</td>
</tr>
<tr>
<td>Imbibition rate</td>
<td>35 or 44% on cane</td>
</tr>
<tr>
<td>Bagasse moisture</td>
<td>50%</td>
</tr>
<tr>
<td>Sugar recovery extraction</td>
<td>97 or 98%</td>
</tr>
<tr>
<td>Exhaust steam pressure</td>
<td>240 kPa(a)</td>
</tr>
<tr>
<td>Evaporators</td>
<td>4 or 5 effect Falling film tubular with multistage distributor</td>
</tr>
<tr>
<td>Boiler steam pressure</td>
<td>10,900 kPa(a)</td>
</tr>
<tr>
<td>Boiler steam temperature</td>
<td>535°C</td>
</tr>
<tr>
<td>Sugar colour</td>
<td>&lt; 45 IU in case of the concepts with attached refinery</td>
</tr>
<tr>
<td></td>
<td>350–600 IU in case of the raw sugar factory concepts</td>
</tr>
<tr>
<td>Factory power consumption for:</td>
<td></td>
</tr>
<tr>
<td>Refined sugar production</td>
<td>25 kWh/t cane for diffuser concepts and 30 kWh/t cane for mill extraction concepts</td>
</tr>
<tr>
<td>Raw sugar production</td>
<td>20 kWh/t cane for diffuser concepts and 25 kWh/t cane for mill extraction concepts</td>
</tr>
<tr>
<td>Final molasses purity</td>
<td>30%</td>
</tr>
<tr>
<td>Overall sugar recovery</td>
<td>89.5–90.5%</td>
</tr>
</tbody>
</table>

An important aspect is a very high sugar recovery of 89.5–90.5%. Many sugar factories compromise on this important benchmark figure and there are many factories achieving sugar recovery efficiencies from 80–85% only. For the calculation of the different process models, the ‘Sugars’ program was employed.

**Technologies employed**

In the following, the most important technologies considered for the concept evaluation are summarised:

- Diffuser plus dewatering mills or milling tandem (6 mills)
- Recycling of clarifier underflow in case of the diffuser models
- Defecation in the juice purification
- Partly direct contact heaters and plate or platular heaters for liquid/liquid applications
- Optimum usage of heating with condensate
- Falling film evaporators
- Stepwise flashing of condensates by ‘condensate cigars’
- CIP (clean in place) system for heaters and evaporators
- Minimisation of evaporator condenser loss
- Batch pans for seed massecuite and refinery products R1, R2 and R3
- Continuous pans for the raw house operation
- Syrup/molasses wash layer system for A sugar
- Crystal seed technology in the raw house
- High pressure boilers with 109 bar and 535°C
- Extraction/condensing turbo alternators
- Fully electrified drives (no steam turbines)

Apart from the mentioned core technologies, it has been assumed that modern equipment is employed and the factory is well designed having good automation.

Arguments for the selection of diffuser versus milling tandem technology have been summarised by Rein (1995, 1999), Mullapudi (2006) and many other authors. In the subsequent chapters, additional background information about some of the aforementioned technologies is given.

**Impact of defecation and sulfitation**

For the production of refined white sugar the defecation process is preferred. If sulfitation is applied in the juice purification stage and eventually for syrup sulfitation, the sugar quality in the raw house can be improved from approx. 350–600 IU to 70–100 IU. This is important for factories producing plantation white sugar for local consumption.

There have been fears in the past that sulfated juices are not suitable for the operation of falling film evaporators as a harder and thicker scale formation could be expected on the evaporator heating surfaces.

This cannot be confirmed. Falling film tubular as well as Falling film plate evaporator trains are operating successfully nowadays with either defecation or sulfitation systems in factories in Brazil, India and Pakistan (Avram et al., 2007).

**Tube/plate heaters versus direct contact heaters**

In order to minimise the process steam demand, indirect and step-wise heating of process flows with tubular or plate heaters is required. However, there are arguments to employ direct contact (DC) heating where applicable because:

1. DC heaters are inexpensive and easy to integrate with low space demand.
2. Allow an approach temperature of 0.5–2 K while tubular or plate heaters require 4-8 K.
3. Almost no cleaning or down time.
5. High load flexibility with minimum performance change.

The juice dilution by injected vapour is of course a drawback of DC heaters. The set-up is crucial as one has to consider that the vapour and the juice system are directly connected and safety measures are required to avoid juice carry over to the condensate system and sugar losses.

The steam on cane demand can be further reduced by 2–3% when only indirect heating with tubular or plate type heaters is employed.

Especially plate heaters require a disciplined and rigid cleaning regime and often do not show the expected performance stated by the suppliers.

For the calculated concepts, direct contact heaters have been considered for raw and limed juice heating as well as clarified juice heating.
It has to be considered that employing DC heaters shifts the requirement for heating surfaces from heaters to the evaporators. The overall investment does not change substantially. It is the operating cost and process performance that favour the DC heaters.

**Evaporator technology**

The most widespread evaporator technology in the cane sugar industry is still the Robert type evaporator with some Kestner applications in selected countries. The process steam demand on cane is limited in these cases to usually 36–40% on cane in the case of raw sugar factories or 45-55% on cane for factories with back-end refineries.

Experience has been gained (Avram et al., 2007, Bhagat, 1996, Journal, 2005, GEA, 2009) in the last 20 years with falling film tubular and later also plate type applications especially in cane sugar mills in Brazil, India and Pakistan with units usually employed in the 1st and 2nd effect (approx. 250–300 units to date). During the past five years, full trains of falling film type evaporators have been introduced.

The authors have been involved in the design of eight plants where exclusively falling film tubular or falling film plate evaporators have been employed. The right evaporator and process engineering design are a crucial aspect here.

The automation of such plants is relatively simple but a well adapted CIP process is required. Good training for local personnel is required to adapt to such new technologies but overall the predicted results have been achieved after an initial learning curve.

Figure 1 displays the k-values (thermal evaporator performance) for Robert, rising film plate, falling film tubular and falling film plate evaporator types (Morgenroth, 2002) in the typical range of applicability in the cane sugar industry.

The k-value is displayed here dependent on the juice viscosity as this parameter is a function of Brix and juice temperature. The plate evaporators show far better efficiencies resulting in less required heating surface and therefore usually less investment.

![Fig. 1—Evaporator performance (k-value) for different viscosities and evaporator types.](image)

On first view, the k-values of Robert and falling film tubular evaporators are not very much different. This is true as long as high temperature differences and high steam consumptions can be accepted.

Figure 2 (Morgenroth, 2002) shows the impact of the specific heat flow density that is correlated to the effective temperature difference. The smaller the specific heat flow, the lower will
be the temperature difference. In the case of rising film evaporators the \( k \)-value does not only depend on the juice viscosity. It depends also very much on the available delta-T or specific heat flow density. If the specific heat flow drops below 7 kW/m\(^2\) heating surface, the thermal performance deteriorates very rapidly.

This is not the case for falling film evaporators where the specific heat flow has practically no impact on the performance. In the case where the overall temperature difference in an evaporation plant is decreased from 125–60°C to 125–90°C, it will not be commercially viable to employ Robert or rising film plate evaporators.

![Fig. 2—Influence of the specific heat flow on the evaporator performance (k-value).](image1)

Figure 3 gives an example for a complete falling film tubular evaporation plant recently installed.

![Fig. 3—Five effect falling film evaporation train in AlMoiz, Pakistan.](image2)
Discontinuous versus continuous pans and other pan house features

Employing continuous pans in the case of low steam demands is not an absolute prerequisite but can offer further optimisation potential.

Actually, continuous pans show their highest benefit when operated with steam pressures in the calandria of 70–90 kPa(a). In this case, the low massecuite head and use of stirrers allow good and smooth performance. The other benefit is the reduction of vapour demand fluctuations because of the constant load profile. However, well designed batch pans equipped with stirrers and operated with low massecuite heads can also be employed without problems with pressures down to 90 kPa(a) without loss in performance.

A new development is the Spray Continuous Pan (SCP) that follows similar lines in comparison to the BMA type VKT with a vertical arrangement (Verma, 2009). Up to now, 14 units of this type are in operation or under construction (Figure 4).

Continuous pans are considered for the concept evaluation for operation with 4th and 5th effect vapour with pressures from 70–100 kPa(a) depending on the scenario.

A high-grade or ‘white’ molasses wash layer system has been considered for the A batch centrifugal station in the raw sugar house. This technology allows reducing the sugar crystal loss from typically 15–25% to 8–12%, thus reducing the steam and power demand of the process. The white molasses used for this purpose does not dissolve much sugar whereas 1 kg wash water dissolves approximately 3 kg of sugar.

A cooling seed crystal system has been considered as well in order to form a uniform seed material for the raw house products. This is especially important for the C-Massecuite seeding as with this technology less high purity material is introduced to the C pans and subsequently lower final molasses purities can be achieved.

Fig. 4—Vertical continuous pans (SCP).
High pressure boilers and turbines

The increase of boiler pressure (and steam temperature) above 4500 kPa(a) does require an improvement of feed water quality and no sugar traces can be accepted any more. Care has to be taken that condensate with a temperature of approximately 120°C is stored under pressure and continuously analysed for sugar traces by flame photometry (potassium based measurement) or TOC (Total Organic Carbon) based on on-line sensors in order to avoid any potential contamination. Typical boiler pressures vary around 6500 kPa(a)/520°C, 9100 kPa/520°C or 10 900 kPa(a)/535°C. Recently, in India, new boiler installations shifted to 10 900 kPa(a) steam pressure, while the highest pressures in Brazil are 9200 kPa(a) nowadays. The selection is influenced by the availability of experienced local boiler manufacturers as well as on the availability and performance of locally or internationally available steam turbines.

Results

The results of the calculations for the different process models are displayed in Tables 1 and 2. The process steam requirement lie in a range of 26–34.2% on cane for the different scenarios.

The diffuser models require approximately 2.5–4% steam on cane more than the milling scenarios. The additional process steam demand for refined sugar production varies from 4.2–5.7% process steam on cane.

The specific power export to the electrical grid varies from 100–122 kWh/t cane.

The diffuser based model offers the advantage of approximately 13–14 kWh/t cane more electrical power export compared to the milling tandem based model.

With the diffuser concept scenarios, it is possible to produce approximately 700–1200 t sugar/year more than with the milling concept scenarios. The reason is the return of the clarifier underflow to the diffuser, eliminating the sugar losses in the filter cake. However, the suitability of this arrangement depends on the cleanness of the cane and requires a multi-fuel boiler because of the higher ash content in the bagasse.

Table 2—Figures for steam, bagasse and power for diffuser-based models.

<table>
<thead>
<tr>
<th>Scenario 1 Diffuser (refined sugar)</th>
<th>Scenario 2 Diffuser (refined sugar)</th>
<th>Scenario 3 Diffuser (raw sugar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar extraction %</td>
<td>98</td>
<td>97</td>
</tr>
<tr>
<td>Imbibition rate % o.c.</td>
<td>44</td>
<td>35</td>
</tr>
<tr>
<td>Operation time crop days</td>
<td>180</td>
<td>180</td>
</tr>
<tr>
<td>Total cane crushed t</td>
<td>1 800 000</td>
<td>1 800 000</td>
</tr>
<tr>
<td>Operation time (off crop) days</td>
<td>140</td>
<td>140</td>
</tr>
<tr>
<td>Process steam on cane (during crop) %</td>
<td>34.2</td>
<td>33.5</td>
</tr>
<tr>
<td>Live steam on cane (crop) %</td>
<td>39.9</td>
<td>38.9</td>
</tr>
<tr>
<td>Total bagasse produced t</td>
<td>532 310</td>
<td>537 624</td>
</tr>
<tr>
<td>Bagasse for stops &amp; losses t</td>
<td>26 616 (~5%)</td>
<td>26 881 (~5%)</td>
</tr>
<tr>
<td>Excess bagasse for off-crop operation t</td>
<td>182 015</td>
<td>194 778</td>
</tr>
<tr>
<td>Annual sugar production (pure sucrose) t</td>
<td>227 866</td>
<td>225 543</td>
</tr>
<tr>
<td>Power production (crop) MW</td>
<td>34.305</td>
<td>33.38</td>
</tr>
<tr>
<td>Power consumption (crop) MW</td>
<td>10.416</td>
<td>10.416</td>
</tr>
<tr>
<td>Power consumption off crop MW</td>
<td>~ 2</td>
<td>~ 2</td>
</tr>
<tr>
<td>Power export crop MWh</td>
<td>103 200</td>
<td>99 213</td>
</tr>
<tr>
<td>Power production off-crop MW</td>
<td>32.454</td>
<td>34.746</td>
</tr>
<tr>
<td>Power export off-crop MWh</td>
<td>102 325</td>
<td>110 027</td>
</tr>
<tr>
<td>Total annual power export MWh</td>
<td>205 525</td>
<td>209 240</td>
</tr>
<tr>
<td>Specific total power export kWh/t cane</td>
<td>114</td>
<td>116</td>
</tr>
</tbody>
</table>
Table 3—Figures for steam, bagasse and power for milling tandem based models.

<table>
<thead>
<tr>
<th></th>
<th>Scenario 4 Mills (refined sugar)</th>
<th>Scenario 5 Mills (refined sugar)</th>
<th>Scenario 6 Mills (raw sugar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar extraction</td>
<td>%</td>
<td>98</td>
<td>97</td>
</tr>
<tr>
<td>Imbibition rate</td>
<td>% o.c.</td>
<td>44</td>
<td>35</td>
</tr>
<tr>
<td>Operation time crop</td>
<td>days</td>
<td>180</td>
<td>180</td>
</tr>
<tr>
<td>Total cane crushed</td>
<td>t</td>
<td>1,800,000</td>
<td>1,800,000</td>
</tr>
<tr>
<td>Operation time off crop</td>
<td>days</td>
<td>140</td>
<td>140</td>
</tr>
<tr>
<td>Process steam on cane (during crop)</td>
<td>%</td>
<td>31.7</td>
<td>29.4</td>
</tr>
<tr>
<td>Live steam on cane (crop)</td>
<td>%</td>
<td>36.8</td>
<td>34.5</td>
</tr>
<tr>
<td>Total bagasse produced</td>
<td>t</td>
<td>523,454</td>
<td>529,330</td>
</tr>
<tr>
<td>Bagasse for stops &amp; losses &amp; bagacillo</td>
<td>t</td>
<td>57,968</td>
<td>58,693</td>
</tr>
<tr>
<td>Excess bagasse for off-crop operation</td>
<td>t</td>
<td>171,420</td>
<td>194,534</td>
</tr>
<tr>
<td>Annual sugar production (pure sucrose)</td>
<td>t</td>
<td>226,860</td>
<td>224,836</td>
</tr>
<tr>
<td>Power production (crop)</td>
<td>MW</td>
<td>31.61</td>
<td>29.72</td>
</tr>
<tr>
<td>Power consumption (crop)</td>
<td>MW</td>
<td>12.5</td>
<td>12.5</td>
</tr>
<tr>
<td>Power consumption off crop</td>
<td>MW</td>
<td>~ 2</td>
<td>~ 2</td>
</tr>
<tr>
<td>Power export (crop)</td>
<td>MWh</td>
<td>82,538</td>
<td>74,390</td>
</tr>
<tr>
<td>Power production off-crop</td>
<td>MW</td>
<td>31.05</td>
<td>35.17</td>
</tr>
<tr>
<td>Power export off-crop</td>
<td>MWh</td>
<td>97,601</td>
<td>111,465</td>
</tr>
<tr>
<td>Total annual power export</td>
<td>MWh</td>
<td>180,139</td>
<td>185,855</td>
</tr>
<tr>
<td>Specific total power export</td>
<td>kWh/t cane</td>
<td>100</td>
<td>103</td>
</tr>
</tbody>
</table>

The imbibition rate was varied from 35–44% on cane resulting in a difference in sucrose extraction rate between 97 and 98%. The power export is affected only by 2–3 kWh/t cane and this shows clearly that usually it is more economic to improve the sugar recovery instead of compromising on the imbibition rate. However, this requires of course sufficient evaporator capacity.

An amount of approximately 5% of the available bagasse has been considered for starts/stops and steam losses. This bagasse can also be partly used for power production but this has not been considered here.

Approx. 1.7% on cane bagacillo has been considered to be lost with the filter mud. In the case of very good cane qualities, the bagacillo amount can drop to less than 0.8% on cane. Often, cane trash is burnt in modern multi fuel boilers today in addition to bagasse.

This can add substantially to the power production and should always be considered for a power plant concept. The evaporation operation scheme for Scenario 4 is displayed as an example in Figure 5.
Fig. 5—Evaporation plant operation Scenario 4.
One of the most important differences between a conventional evaporation set-up and the given scenarios is the small effective delta-T with special regard to the last two effects. It has been stated in the past that the higher temperatures in the last effects could cause high sugar losses or colour formation.

Practical experience has shown that this is not the case and supports the known facts of slower sucrose degradation and colour formation (Vukov, 1965; Vukov and Patkai, 1981) in the case of juice temperatures below 110°C.

The juice residence times in a falling film evaporation plant are approx. 25–35 minutes compared to Robert-based trains where often more than 60 minutes residence times can be observed (Morgenroth, 2002). This allows operation at slightly higher temperatures in the initial effects that are more sensitive concerning sugar losses.

There are cases where an investment into high pressure boilers might not be viable. However, bagasse itself is nowadays a valuable product that can be sold for good prices. Therefore, it makes sense to optimise the process.

Conclusions

A steam on cane demand from 26–34% steam on cane (260–340 kg steam/t cane) can be considered nowadays as a benchmark for a modern cane sugar factory supplying also ‘green power’ to the electrical grid. Electrical power exports of 100–120 kWh/t cane to the power grid can be considered as technically and economically feasible.

It might be assumed that a modern factory concept requires higher investment cost. In our experience, this has not been proven as the reduction in steam demand–compared to conventional designs–of approx. 20% on cane or ~ 40% in total reduces the investment in boilers and turbines substantially allowing additional investment in other areas.

First experience has been gained with such innovative designs in a few mills in Brazil, India and Pakistan and especially the success of the falling film evaporator technology has been proven very well under quite different operating conditions.

REFERENCES


CONCEPTS POUR UNE TRÈS FAIBLE DEMANDE DE VAPEUR À LA SUCRERIE ET L'ÉVOLUTION DE SON IMPLEMENTATION

Par

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MOTS-CLEFS: Cogénération, l'Efficacité de la Vapeur, Normes d’Energie.

Résumé

L'EXPORTATION d’énergie des usines de canne à sucre permet la production ‘d’énergie verte’ et s'avère aujourd'hui comme une source importante de revenu. En vue du potentiel de cogénération de l'industrie, l'exportation d'énergie est en fait à un stade très précoce. Ce rapport donne un aperçu sur les concepts et les mesures qui sont nécessaires pour obtenir une faible demande de vapeur et une forte exportation de puissance électrique avec des usines différentes. L’impact de l’extraction aux moulins ou avec une diffusion ainsi que l'option de production du sucre raffiné dans une raffinerie attachée à la sucrerie sont étudiés. Les modèles étudiés permettent de réduire la demande de vapeur vers une plage de 26–34% sur la canne. Ces concepts ne sont plus théoriques, mais ont été mis en œuvre et éprouvées avec succès dans plusieurs sucreries en Inde, au Brésil et au Pakistan au cours des cinq dernières années. Le rapport donne un aperçu des résultats obtenus.

CONCEPTOS PARA UNA BAJA DEMANDA DE VAPOR EN FÁBRICA Y ESTADO DE IMPLEMENTACIÓN

Por

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PALABRAS CLAVE: Cogeneración, Eficiencia Energética, Vapor, Benchmarking

Resumen

LA EXPORTACIÓN de energía eléctrica desde los ingenios cañeros permite la producción de ‘energía verde’ y se manifiesta también como una fuente sustancial de rentabilidad. Observando el potencial de cogeneración de industria de la caña, la exportación de energía eléctrica se encuentra aún en una etapa muy primaria. Este trabajo presenta un repaso sobre conceptos y medidas que se requieren para lograr una baja demanda de vapor y alta capacidad de cogeneración para diferentes conceptos de fábrica. Se investiga el impacto de la extracción con molinos y difusores también como la opción de producir azúcar refinado en una refinería anexa. Los modelos de fábricas investigados permiten demandas de vapor %caña de 26–34%. Tales conceptos de fábrica no son teóricos ya y han sido probados exitosamente en plantas de India, Brasil y Pakistán en los últimos cinco años. Se presenta un reporte de los logros reales alcanzados.
ENGINEERING PROPERTIES OF SUGARCANE FIBRES

By

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Abstract

THE PHYSICAL properties and the mass and heat transfer coefficients for sugarcane bagasse were determined to provide information for process design and manufacturing of products. In this report, true density ($\rho_s$) and apparent density ($\rho$) were measured by the pycnometer method. Superficial area ($A_s$) and pore size distribution of fibres were determined by nitrogen adsorption and mercury porosimetry. Equilibration cells were used in order to obtain sorption isotherms. Water content and surface temperature of the sugarcane fibres were monitored using a modified Thermal Gravimetric Analyzer (TGA). The method of slope was used to calculate the effective water diffusion coefficient. The mass ($h_M$) and heat coefficients ($h_H$) were determined by experimental data, and then compared with one convective transfer correlation. The results showed that the parameters of the GAB equation adequately represent the experimental data. The order of magnitude of $D_e$ of fibres was $10^{-10}$ m$^2$/s. The value of $h_H$ was 40 W/(m$^2$ °K) and $h_M$ was 0.045 kg/(m$^2$.s). The fibre is a porous material consisting of macropores and its internal structure differs from that of the pith. The experimental values of $h_H$ were more elevated than those calculated with correlations due to the effects of conduction and radiation. The principal mass transfer mechanism was the internal resistance, $D_e$ increased with temperature in an Arrhenius type function.

Introduction

Bagasse is the residue left after the crushing of sugarcane for juice extraction. The largest and most traditional use of bagasse is burning it in boilers to generate process steam (Nassar et al., 1996).

A revision of the published results and industrial experience realised by Atchison (1971, 1974) and Pilgrim (1989) has shown the viability of satisfying the energy needs of a sugar factory with half of its residual bagasse. Then, the remainder can be used in more than 40 applications; the most important are paper pulp and cellulose pulp production, animal food, ethanol, and furfural.

In order to expand the use of bagasse, it is essential that information on fibre characteristics and the factors which affect the performance of that fibre be available.

Specific knowledge of the bagasse material is useful to predict its behaviour during transformation processes. Physical properties involved in the heat and mass transfer, such as density and porosity, play an important role in the design, the estimation of other properties, the characterisation of materials, and the prediction of heat transfer operations during processing and handling.
The engineering properties are important in the process design and manufacturing of products. The mathematical models are fitted using data as a function of one or more experimental parameters, such as temperature, water content, porosity, heat, and mass transfer coefficients or others. In order to do this, the aim of the present work is to describe physical characteristics, adsorption capacity, mass and heat transfer coefficient and water diffusivity of bagasse.

**Materials and methods**

**Material preparation**

The sugarcane bagasse provided by sugarcane factories in Zacatepec, Morelos, Mexico was depithed while wet, dried, sieved, and classified by size manually using a stereoscopic microscope. The highest frequency fractions (9.62% and 7.53%) of fibre (12 to 14 and 20 to 24 mesh screen/sieve, respectively) were used for all tests. A vernier caliper was used for measuring the length and diameter of the selected fibres. Volume and area were calculated using these data. Physical characteristics are shown in Table 1.

<table>
<thead>
<tr>
<th>Number of fibres measured</th>
<th>Average diameter</th>
<th>Average length</th>
<th>Average area</th>
<th>Average volume</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mm</td>
<td>mm</td>
<td>mm²</td>
<td>mm³</td>
</tr>
<tr>
<td>40</td>
<td>0.362 ± 0.01</td>
<td>7.492±0.14</td>
<td>8.52</td>
<td>0.970</td>
</tr>
<tr>
<td>14</td>
<td>0.5483 ±0.03</td>
<td>10.186±0.19</td>
<td>17.55</td>
<td>2.40</td>
</tr>
</tbody>
</table>

**Heat and mass transfer convective coefficient**

A heat and mass balance expressed by equation 1 (Vaccarezza et al., 1974) was used to determine the experimental convective heat and mass coefficients. All symbols are described in the Notation section at the end of this paper.

**Equation 1**—Heat balance equation.

\[
\Delta H_v \frac{dX}{dt} = h \cdot A \cdot \Delta T
\]

Experiments were conducted to measure the moisture lost during drying. The rate of moisture lost \( \frac{dX}{dt} \), determined in the period of constant-rate drying, and fibre surface temperature data were used for determine the convective coefficients of heat and mass transfer. It is assumed the heat of water vaporisation is constant and equal to the heat of water vapour condensation.

A correlation presented by Eckert and Drake (1959) was used for the calculation of the local heat transfer coefficient around the periphery of thin cylinders in the laminar region for flow of a fluid with constant thermophysical properties. For Reynolds numbers 0.1 to \( 10^5 \) and Prandtl numbers of 0.7 to 1500, the heat transfer coefficient correlation is expressed by equation 2.

**Equation 2**—Heat transfer coefficient correlation,

\[
Nu = 0.43 + 0.532 \cdot Re^{0.5} \cdot Pr^{0.31}
\]

The Nu and Re numbers were calculated with the fluid properties measured at the mean temperatures of the solid and of the fluid.

An analogous expression for the mass transfer coefficient is shown in equation 3.

**Equation 3**—Mass transfer coefficient correlation.

\[
Sh = 0.43 + 0.532 \cdot Re^{0.5} \cdot Sc^{0.31}
\]
Calculation of the effective moisture diffusivity

The effective moisture diffusivity \( (D_e) \) in solids is a physical property of the system and can be estimated from drying rate data. Assuming that the drying process is entirely controlled by internal mass transfer resistance (falling rate drying period), uniform initial moisture distribution and negligible external resistance, the solution of Fick’s diffusion equation developed for particles with cylinder geometry by Crank (1975) for a series of six terms is applicable and is in the form of equation 4.

**Equation 4**—Solution of Fick’s diffusion equation for a cylinder.

\[
W = 2 \cdot \sum_{i=1}^{5} \int^{1}_{0} f_0\left( \alpha_i \cdot r \right) \, dr \cdot \exp \left( -F \alpha_i \cdot \alpha_i^2 \right)
\]

The effective moisture diffusivity was calculated using the slope method (Perry et al. 1984)

Physical properties

**True and apparent density**

The true density was calculated from the volume measured by a gas pycnometer. A dried, pre-weighed sample was placed in an autopycnometer (MicroMeritics AccuPyc 1330). Helium was used as the displacement fluid. The apparent density of the totally-dried fibres was determined by measuring their dimensions and weight.

**Surface area and pore size**

The size, area and pores distribution were measured by nitrogen adsorption and mercury porosimetry methods, respectively. A nitrogen adsorption surface area analyser (Micromeritics, ASAP-2000) and standard methods ASTM D 3663-92 and ASTM D 4222-91 were used to evaluate the surface area and pore size, and adsorption and desorption by nitrogen isotherms. A mercury porosimeter (Poromaster, Quantachrome) was used between 0 and 60,000 psi for measured macropores. The pore volume distribution over pore diameter is expressed in terms of the distribution function \( F_v \) (eq. 5):

**Equation 5**—Pore volume distribution function.

\[
F_v = \left[ \frac{dV}{d\log D} \right]
\]

where \( V \) is pore volume. The function is such that area under the function in any pore diameter range yields volume of pores in that range.

**Sorption isotherms**

Sorption isotherms were determined gravimetrically at 25°C and 70°C. Triplicate samples of fibres dried at 90°C, sieved on sieves mesh number 16–14 (1.19–1.41 mm) and weighed, were transferred to vacuum desiccators.

Sulfuric acid solutions at different concentrations were used to achieve the internal, relative humidity in desiccators (Iglesias and Chirife, 1982; Molnár, 1995) over the range of 4% to 80% water activity \( (a_w) \). The criterion for the stable state was that water content of the samples (dry basis) did not change more than 2 mg/g during three consecutive days.

The Guggenheim-Anderson-DeBoer (GAB) equation (eq. 6) was used in modelling water sorption (van den Berg and Bruin, 1981):

**Equation 6**—The Guggenheim-Anderson-DeBoer (GAB) equation

\[
X = \frac{X_m \cdot C \cdot K \cdot a_w}{(1-K \cdot a_w) \cdot (1-K \cdot a_w + C \cdot K \cdot a_w)}
\]
The water activity, $a_w$, is defined as the ratio of the partial pressure, $p_w$, to the vapour pressure of water $p_w(0)$ at equilibrium (Rao and Rizvi, 1986). Temperature dependent GAB constants $C$ and $K$ were calculated with the following equations:

**Equation 7**—Temperature dependent GAB constant.

\[
C = C_0 \cdot \exp\left[\frac{\Delta H_C}{R \cdot T}\right]
\]

\[
K = K_0 \cdot \exp\left[\frac{\Delta H_K}{R \cdot T}\right]
\]

**Results**

**Fibre dimensions**

Surface area, pore and diameter volume measured by nitrogen adsorption and mercury porosimetry are shown in Table 2. True density of fibres was 1.331 g/cm$^3$. The order of magnitude is consistent with those of some natural fibres and similar to jute, banana, kenaf, coconut, and sisal (Eichhorn et al., 2001; Biagiotti et al., 2004). Porosity, calculated from true density and pore volume was 0.714. The pore distribution is shown in Figures 1 and 2 for the two measurement methods used.

**Table 2**—Measured fibre properties

<table>
<thead>
<tr>
<th>Properties</th>
<th>Nitrogen adsorption</th>
<th>Mercury porosimetry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superficial area (m$^2$/g)</td>
<td>1.300</td>
<td>5.8267</td>
</tr>
<tr>
<td>Pore volume (cm$^3$/g)</td>
<td>0.0426</td>
<td>1.8733</td>
</tr>
<tr>
<td>Pore average diameter (μm)</td>
<td>0.0385</td>
<td>1.285</td>
</tr>
</tbody>
</table>

![Fig. 1—Fibre pore distribution (mercury porosimetry).](image)
The distribution of pore sizes was represented by the logarithmic derivative of the cumulative intrusion of mercury volume V (dV/dlogD) vs pore diameter (D). The nitrogen absorption method shows lower results than the mercury porosimetry method. The difference is explained by the measurement range of each method. The first method has a range of micropores to mesopores of between 10–500 Å while the second method has a range of mesopores to macropores greater than 500 Å.

The pore volume distribution over pore diameter is expressed in terms of the distribution function Fv. The fibres reveal two pore distributions, one in the range of 0.1 at 1 μm and one in the range 4–100 μm with pore diameter maxima of 0.5774, 5.387 and 29.85 μm. This material mainly contains macropores >0.05 μm.

Fig. 2—Fibre pore distribution (nitrogen adsorption method).

**Sorption isotherm**

The values of GAB constant and the correction factors are presented in Table 3. The water adsorption isotherm results plotted for the fibre were carried out at 25°C and 70°C and are presented in Figure 3.

The isotherm presents a sigmoid or S-shape. For the same moisture content, water activity increased with temperature. This behaviour is frequently observed in cellulose-based materials (Jonquières and Fane, 1998).

The high level of moisture adsorption is caused by the high hydrophilic nature of the sugarcane fibre compared to other natural fibres, like the agave fibre which shows a low adsorption of 0.3 g water/g dry fibre at 0.8 a_w (Bessadok, 2009).

Cane fibre has a high cellulose composition of 32–48 % (Rowell et al., 2000) and therefore a number of accessible –OH groups that are responsible for the negative charge and the best characteristics of sorption.
Table 3—GAB constants.

<table>
<thead>
<tr>
<th>GAB constants</th>
<th>25°C</th>
<th>70°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_m$</td>
<td>3.6511</td>
<td>4.2061</td>
</tr>
<tr>
<td>$C$</td>
<td>4.206</td>
<td>5.4379</td>
</tr>
<tr>
<td>$K$</td>
<td>$82.57 \times 10^{-4}$</td>
<td>$103.73 \times 10^{-4}$</td>
</tr>
<tr>
<td>$C_0$</td>
<td>29.8235</td>
<td>29.8235</td>
</tr>
<tr>
<td>$K_0$</td>
<td>0.04702</td>
<td>0.04702</td>
</tr>
</tbody>
</table>

Mass and heat transfer

The experimental heat and mass transfer coefficients were larger than those typically used in correlations. This could be explained because other factors like thermal conduction and radiation are involved in the experimental tests (Table 4).

The values of effective diffusivity for different experimental conditions are presented in Table 4. These values are within the general range of $10^{-11}$ for dry food materials and lower than the reported values of $3.92 \times 10^{-12}$ m$^2$/s for sisal at 30% relative humidity (Alvarez et al., 2004).

The mass transfer Biot number values were higher than 50. Therefore, the controlling mechanism of mass transport is the internal resistance to the transfer of humidity. Both internal and external resistance are important for heat transfer (Biot less 50).

![Fig. 3—Fibre sorption isotherm.](image-url)
Table 4—Mass and heat transfer coefficients

<table>
<thead>
<tr>
<th>Experimental conditions</th>
<th>$h_h$</th>
<th>$h_m$</th>
<th>$D_e$</th>
<th>$B_{H}$</th>
<th>$B_{M}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp.</td>
<td>m/s</td>
<td>Fibre diameter</td>
<td>Correlation</td>
<td>Exp. Correlation</td>
<td>Exp.</td>
</tr>
<tr>
<td>C</td>
<td>m</td>
<td>(W/(m² °K))</td>
<td>(kg/(m² s))</td>
<td>m²/s</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>70</td>
<td>0.35</td>
<td>0.552</td>
<td>30.58</td>
<td>46.70</td>
<td>0.034</td>
</tr>
<tr>
<td>70</td>
<td>0.80</td>
<td>0.366</td>
<td>48.99</td>
<td>32.67</td>
<td>0.055</td>
</tr>
<tr>
<td>80</td>
<td>0.35</td>
<td>0.552</td>
<td>30.93</td>
<td>39.80</td>
<td>0.035</td>
</tr>
<tr>
<td>80</td>
<td>0.35</td>
<td>0.552</td>
<td>30.91</td>
<td>41.34</td>
<td>0.035</td>
</tr>
<tr>
<td>90</td>
<td>0.35</td>
<td>0.552</td>
<td>31.43</td>
<td>46.32</td>
<td>0.035</td>
</tr>
<tr>
<td>90</td>
<td>0.80</td>
<td>0.366</td>
<td>50.36</td>
<td>39.39</td>
<td>0.056</td>
</tr>
<tr>
<td>90</td>
<td>0.35</td>
<td>0.552</td>
<td>45.49</td>
<td>40.66</td>
<td>0.051</td>
</tr>
<tr>
<td>90</td>
<td>0.80</td>
<td>0.552</td>
<td>35.61</td>
<td>51.27</td>
<td>0.040</td>
</tr>
<tr>
<td>110</td>
<td>0.35</td>
<td>0.552</td>
<td>32.19</td>
<td>40.53</td>
<td>0.035</td>
</tr>
<tr>
<td>120</td>
<td>0.35</td>
<td>0.552</td>
<td>47.68</td>
<td>44.13</td>
<td>0.052</td>
</tr>
<tr>
<td>120</td>
<td>0.80</td>
<td>0.366</td>
<td>36.63</td>
<td>55.58</td>
<td>0.040</td>
</tr>
<tr>
<td>120</td>
<td>0.35</td>
<td>0.552</td>
<td>32.64</td>
<td>46.92</td>
<td>0.036</td>
</tr>
<tr>
<td>130</td>
<td>0.35</td>
<td>0.552</td>
<td>33.10</td>
<td>53.45</td>
<td>0.036</td>
</tr>
</tbody>
</table>

Conclusions

The dimensions of the fibre, physical properties, and mass and heat transfer coefficients of cane fibre bagasse were studied. The fibres are made up mainly of macropores distributed essentially in two pore diameters.

The analysis of the water sorption indicates that the fibre is highly hydrophilic. This behaviour is a result of its high cellulose composition and is consistent with other cellulose fibres. The GAB model gives a good fit to the water adsorption data.

The heat and mass transfer coefficients, determined by experimental tests and correlations, show differences. The explanation of this behaviour would be the effect of thermal conduction and radiation.

The controlling mechanism of mass transport is the internal resistance to humidity transfer and, for heat transfer, internal and external resistance are important.

Acknowledgments

The authors thank the Instituto Politécnico Nacional-México, the Instituto Mexicano del Petroleo for the mercury porosimetry tests, and COTA for the nitrogen adsorption tests.

Notation

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Area [m²]</td>
</tr>
<tr>
<td>As</td>
<td>Superficial area [m²/kg]</td>
</tr>
<tr>
<td>$a_{w}$</td>
<td>Water activity</td>
</tr>
<tr>
<td>$B_{H}$</td>
<td>Biot number (heat)</td>
</tr>
<tr>
<td>$B_{M}$</td>
<td>Biot number (mass)</td>
</tr>
<tr>
<td>C</td>
<td>GAB parameter</td>
</tr>
<tr>
<td>$C_{0}$</td>
<td>GAB parameter</td>
</tr>
<tr>
<td>$c_{p_{a}}$</td>
<td>Specific heat capacity [J/kg°K]</td>
</tr>
</tbody>
</table>
Particle diameter \([m]\)

Pore diameter \([cm]\)

Molecular diffusivity \([m/s]\)

Effective moisture diffusivity \([m^2/s]\)

Fourier number \(\frac{T}{D}\)

Heat transfer coefficient \([W/m^2°K]\)

Mass transfer coefficient \([kg/m^2s]\)

Bessel function of the first kind of order 0

Bessel function of the first kind of order 1

Thermal conductivity of air \([W/m^2°K]\)

Thermal conductivity of solid \([W/m^2°K]\)

GAB parameter

GAB parameter

Nusselt number \(\frac{h \cdot d}{k_s}\)

Pressure \([Pa]\)

Air molecular weight \([g/mol]\)

Prandtl number \(\frac{cp \cdot \mu_s}{k_s}\)

Partial pressure of water vapour \([Pa]\)

Vapor pressure of water at equilibrium \([Pa]\)

Radial coordinate \([m]\)

Particle radius \([m]\)

Universal gas constant \([kJ/mol°K]\)

Reynolds number \(\frac{d \cdot v \cdot \rho_s}{\mu_s}\)

Schmidt number \(\frac{\mu_s}{\rho_s \cdot D_{AB}}\)

Sherwood number \(\frac{h \cdot R \cdot T \cdot d}{P \cdot PM_a \cdot D_{AB}}\)

Temperature \([^°K]\)

Time \([min]\)

Air rate \([m/s]\)

Volume \([cm^3]\)

Water content \(\frac{X-X_e}{X_e-X_c}\) dimensionless

Water content (dry base) \([kg\ water/kg\ dry\ solid]\)

Critical water content (dry base) \([kg\ water/kg\ dry\ solid]\)

Equilibrium water content (dry base) \([kg\ water/kg\ dry\ solid]\)

Monolayer water content \([kg\ water/kg\ dry\ solid]\)

Root of the Bessel function of the first kind of order 0

GAB equation parameter \([J/mol°K]\)

GAB equation parameter \([J/mol°K]\)
ΔHv Latent heat of vaporisation [J/kg]
ρ Apparent density [kg/m³]
ρa Air density [kg/m³]
ρs True density [kg/m³]

REFERENCES
PROPRIÉTÉS PHYSIQUES DES FIBRES DE CANNE A SUCRE

Par

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MOTS-CLEFS: Propriétés Physiques, Fibres de Canne a Sucre, Coefficients de Transfert Massique et Thermal.

Résumé
LES PROPRIÉTÉS physiques de la bagasse et les transferts de masse et de chaleur ont été déterminés afin de fournir des informations pour les processus de conception et pour la fabrication de produits. Dans ce rapport, la densité réelle ($\rho_s$) et la densité apparente ($\rho$) ont été mesurées avec un pycnomètre. La superficie (As) et la distribution de taille des pores de fibres ont été déterminées par adsorption d'azote et par porosimétrie. Des cellules d'équilibre ont été utilisées afin d'obtenir des isothermes. La température de surface et la concentration d'eau de la fibre ont été déterminées avec un Thermal Gravimetric Analyzer (TGA). La méthode de pente a été utilisée pour calculer le coefficient de diffusion de l'eau. Les coefficients de masse ($h_M$) et de chaleur ($h_H$) ont été déterminés par les données expérimentales et puis comparées par corrélation. Les résultats montrent des valeurs $\rho_s$ de 1231 kg/m$^3$, $\rho$ de 466 kg/m$^3$ et As de 1300 m$^2$/kg. La fibre de canne est constituée principalement par des macro pores d'un diamètre moyen de 0.0385 μm. Les isothermes de sorption sont du type II sigmoïde, un formulaire qui est compatible avec les structures macro pores. Les résultats montrent que les paramètres de l'équation de GAB représentent convenablement les données expérimentales. L'ordre de grandeur pour le $D_e$ des fibres est $10^{-10}$ m$^2$/s. La valeur de $h_H$ était 40 W/(m$^2$.°K) et celle de $h_M$ 0.045 kg/(m$^2$.s). La fibre est un matériau poreux, composé de macro pores et sa structure interne diffère de celle de la moelle. Les valeurs expérimentales de $h_H$ étaient plus élevés que celles calculées par corrélations due aux effets de conduction et rayonnement. Le mécanisme principal du transfert de masse était la résistance interne, $D_e$ a augmenté avec la température en fonction de l’équation d’Arrhenius.
PROPIEDADES DE INGENIERÍA DE LAS FIBRAS DE LA CAÑA DE AZÚCAR

Por

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PALABRAS CLAVE: Propiedades Físicas, Fibras de Caña de Azúcar, Coeficientes de Transferencia de Calor y Masa.

Resumen
SE DETERMINARON las propiedades físicas y los coeficientes de transferencia de calor y de masa del bagazo para suministrar información para diseño de proceso y fabricación de productos. En este trabajo se midieron la densidad real (ρs) y aparente (ρ) con el método del picnómetro. El área superficial (As) y el tamaño y distribución de fibras se determinaron por adsorción de nitrógeno y la distribución de los tamaños de poros de las fibras se determinó por adsorción de Nitrógeno y porometría de Mercurio. Para la obtención de las isotermas de adsorción se usaron celdas de equilibrio. El contenido de agua y la temperatura superficial de las fibras de caña se monitoreó con un Analizador Termogravimétrico modificado (TGA). El coeficiente efectivo de difusión de agua se calculó por el método de la pendiente. El coeficiente de transferencia de masa (hM) y el coeficiente de transferencia de calor (hH) se determinaron con datos experimentales y se compararon con una correlación de transferencia convectiva. Se obtuvieron valores de ρs de 1231 Kg./m3, ρ de 466 kg/m3 y As de 1300 m²/Kg. Las fibras de caña están formadas principalmente por micropores con un diámetro promedio de 0.0385 μm. Las isotermas de adsorción son del tipo II de forma sigmoide, consistente con las estructuras macroporosas. Los resultados mostraron que los parámetros de la ecuación GAB representan adecuadamente los datos experimentales. El orden de magnitud para el De de las fibras fue 10⁻¹⁰ m²/s. El valor de hH fue 40 W/(m².°K) y hM fue 0.045 Kg./(m².s). La fibra es un material poroso formado por macroporos y su estructura interna es diferente de la de la médula. Los valores experimentales de hH fueron más elevados que los calculados con correlaciones debido a los efectos de conducción y radiación. El principal mecanismo de transferencia de masa fue la resistencia interna, y De se incrementó con la temperatura en una función del tipo Arrhenius.
CANE PREPARATION—OPTIMISED TECHNOLOGY

By

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KEYWORDS: Shredder, In-Line, Preparation, Cane.

Abstract

FIVES CAIL has developed and improved its cane preparation technology to meet the requests of modern cane sugar and ethanol factories who either want to upgrade their factories or build new ones; the major concerns being investment, performance, energy and operation. Fives Cail now has more than 30 installations of the in-line shredder in Africa, Asia and the Americas, and has continually improved and developed the design to extend the range up to a capacity of 825 tonnes cane crushed per hour, while at the same time simplifying the original designs of feed drum, rotor, hammers and anvil plate and increasing the capacity for a given carrier width. The in-line shredder technology consists of two main pieces of equipment; a cane leveller (or carding drum) and the shredder assembly, which allows for a very simple and uncomplicated installation that can be either incorporated into an existing cane carrier or installed in a new one. Its construction is modular with a small footprint. The in-line shredder will process either whole stick or billeted (short) cane or any combination of the two, and can operate in all possible conditions including the preparation of washed cane, and also cane containing a high quantity of sand or rocks. All results shown have been obtained directly from the factories, either through official channels or from personal visits by Fives Group personnel. As with all results collected under non-laboratory conditions, some approximation may be assumed; however, they tend to show fairly consistent figures. It can therefore be concluded that after several years of continual development and improvement, research and results show there are several genuine benefits, both direct and indirect, to be gained from incorporating the in-line shredder technology into a factory in order to upgrade the cane preparation performance. Benefits can be seen in terms of reduced installation costs, reduced maintenance costs, and reduced overall power consumption over more conventional cane preparation equipment.

Introduction

Cane preparation is often overlooked in a factory’s quest for general improvement in efficiency and performance when in actual fact, in the factory environment, it is probably one of the most important factors in achieving both of these. In terms of improving and increasing overall factory output, it is very probably one of the cheapest ways to do so. By improving the cane preparation from say a preparation of 75% to a preparation index above 90%, the increase in throughput, overall extraction and reduction in pol % bagasse is similar to the figure that would be expected when adding an extra mill to the crushing line, at approximately 60% of the equipment price (more if civils and drives are taken into account).

Historical

There have been few major developments in cane preparation since the introduction of the heavy duty gravity-fed shredders in the late 1960s. In order to achieve a preparation index above 90%, a typical cane preparation station for long cane comprises the following:
• 1 × leveller (1st) knife set (50 mm pitch)
• 1 × heavy duty (2nd) knife set (25 mm pitch)
• 1 × cane kicker
• 1 × gravity shredder

The cane knives are required to prepare and more importantly chop the whole-stick cane to a suitable condition to feed into a gravity shredder in order to avoid choking.

A typical installation drawing is shown in Figure 1.

![Fig. 1—A typical whole-stick cane preparation station with gravity-fed shredder.](image)

To obtain consistent preparation, the 1st knives would be positioned on an auxiliary carrier approximately 250 mm from the surface of the slats to prepare the top half of the cane bed. The part-prepared cane would be tumbled onto a 2nd (main) carrier passing through a set of heavy duty knives preparing the remaining cane to a preparation index of around 65%, before feeding into a heavy duty shredder from a height of 6 m to 7 m.

The shredded cane would then be transported to the 1st mill. The Fives Fletcher recommended installed powers in order to guarantee a preparation index of over 90% with this specification would be as follows:

- No.1 knives 11 kW.h/t fibre
- No. 2 knives 14 kW.h/t fibre
- Cane kicker 30 kW
- Gravity shredder 45 kW.h/t fibre

So, typically for a 2135 mm wide carrier and considering a cane rate of 400 t/h at 15% fibre content, the total installed preparation power would be 4230 kW.

**Contra-rotating knives**

Several manufacturers produce contra-rotating cane preparation devices, fitted with either swivelling hammers or fixed knives, and operated with a washboard. These devices can be fitted in place of the No.2 knife set to reduce the installation requirements in terms of the number of carriers required and hence overall space. Contra-rotating knives are especially useful in areas with rock problems as they tend to chip away the rocks. However, the installed power does increase as shown below.

- No.1 knives 11 kW.h/t fibre
- Cane preparator 25 kW.h/t fibre
- Gravity shredder 45 kW.h/t fibre

Again, for a 2135 mm wide carrier and considering a cane rate of 400 t/h at 15% fibre content, the total installed preparation power would be 4860 kW and the configuration is shown in Figure 2.
The requirements of a modern sugar and ethanol factory

Increasingly for the front end, clients are looking for the following advantages:

- Reduction in overall energy consumed
- Increased productivity and throughput
- Reduction in downtime
- Reduced maintenance periods and costs
- Increase in factory performance
- Cost effective changes

In-line shredder

Fives Cail developed and installed some of the first in-line shredders in the 1990s, and these designs have been constantly updated, re-designed and further developed into the present range of shredders.

The in-line shredder has been designed to process either long or short cane (in any ratio) and without the need for pre-preparation, so no cane knives are required prior to the shredder.

The shredder assembly consists of three main components, the feed drum, the shredder rotor and the anvil plate (Figure 3). In addition to these, two auxiliary pieces of equipment are required to ensure consistent feed of cane to both the shredder and No.1 mill; a carding drum and a shredded cane kicker (see Figure 4).
Carding drum
The carding drum contra-rotates against the cane flow and is responsible for two operations
- Metering flow: The carding drum acts as a metering device, holding back excessive amounts of cane in the carrier and ‘filling-in’ sparse areas, therefore providing a consistent flow of cane at the calculated carrier speed and cane density to maintain a consistent crush rate.
- Increasing compaction: The density of long cane fed into a carrier normally averages between 125 kg/m³ and 150 kg/m³. The carding drum is designed to be set at a specific height, based on carrier speed and cane throughput, to achieve the required cane compaction after the drum. The resulting cane mat is therefore at a consistent density which ensures the correct approach angle can be achieved of the cane mat relative to the feed drum. For 100% short cane, the carding drum would be used to ‘wipe-off’ the cane bed to achieve the correct calculated height for the capacity required. No additional compaction would take place.

Only one carding drum is normally required to obtain the required compaction for installation on carriers from 0 to 10 degrees. Two carding drums are recommended at angles in excess of 10 degrees and also in situations where the cane feeding is difficult to control, for instance if substantial manual and unmonitored cane feeding is allowed after the feed tables.

Feed drum
The feed drum co-rotates with the cane flow and is responsible for providing positive feed of the cane mat into the rotor and also increasing the compaction of the cane to avoid the whole stalk being swept into the anvil. The drum ‘traps’ the mat of cane against the carrier slats, increasing the compaction of cane to between 280 kg/m³ to 350 kg/m³, thus allowing the rotating hammers to ‘wipe-off’ a section of cane from the long stalks. It is most important to keep the cane entry to the drum at a good angle, to maximise throughput while keeping the carrier speed as low as possible for the required capacity. Excessive entry angles can create cane feed problems and results in drum judder which would ultimately cause increased peak loads on both drives and bearings, leading to premature failure. The peripheral speed of the feed drum is set higher than the linear speed of the carrier to provide positive feed of cane to the hammers.
Rotor

These shredders are available with two types of rotor design, either six-row or eight-row; both types incorporate alternately staggered profiled plates. The six-row design has a swept hammer diameter of 1680 mm while the eight-row swept hammer diameter is 1900 mm. Figure 6 shows capacities for both types of rotor. All the rotors should have in excess of 100% full coverage of the hammers and ideally use high grade stainless steel tie rods and hammer bars for extended life expectancy and strength. The tie rods should be tightened to specific torque ratings using hydraulic tensioning devices.

Hammers

Hammers are manufactured from 55 mm or 60 mm thick high strength, low alloy structural steel plate preferably cut along the grain of the steel. Hard facing is applied to the hammer extremities to a minimum 3 mm thickness on the facing to give a wear resistant layer of material. The specification for the weld deposit is dependent on the operating conditions expected at site; (excessive sand or rocks would dictate different materials). Normal weight for the hammers on a Fives Cail shredder is 22 kg and life expectancy is dependent on many things, but normally 14 days between hammer changes is a reasonable expectation.

Anvil plate

The entry distance between the rotor and anvil is normally fixed at around 40 mm, with adjustment at the exit side of the anvil plate being possible as required. The anvil plate adjustment bars are also fitted with shear pins to protect the rotor and grid bars in case large objects should pass through the shredder. The angle of wrap is approximately 75 degrees.

Kicker

The shredded cane is very dense and wet when it is deposited back onto the cane carrier, and tends to stick to the slats at the head end and causing uneven feed onto the resulting conveyor or carrier. To overcome this uneven feed, the installation of a shredded cane kicker is always recommended if at all possible. This kicker breaks up the cane mat, reducing the shredded cane density, and improving the consistency feed into No.1 mill intercarrier.

A typical installation is shown in Figure 5.

![Fig. 5—A typical cane preparation station with in-line shredder.](imageurl)
Again, for a 2135 mm wide carrier and considering a cane rate of 400 t/h cane at 15% fibre content, the total installed power would be 3180 kW.

**Capacity**

Fives Cail manufactures in-line shredders of both six-row (1680 mm diameter) and eight-row (1900 mm diameter). Figure 6 below shows the general capacities for the two diameters of shredder when compared with the width of the cane carrier.

The blue line represents the theoretical capacity of the 1680 mm diameter shredder rotor and the red line represents the theoretical capacity of the 1900 mm. These figures are approximate and based on cane containing 15% fibre. Every proposed installation, however, should be treated on an individual basis.

![In line shredders](image)

**Tip speed**

The calculated tip speed for the shredder is set between 88 m/s and 99 m/s, which gives a good compromise between cane preparation and hammer life.

On the 1.9 m diameter rotor, both 50 Hz and 60 Hz electric motors can operate at synchronous speed (at either 900 r/min or 1000 r/min) with no need for gear reduction.

The 1.68 m diameter rotor operates within the desired range at 60 Hz (88 m/s) and, although the tip speed is slightly slow when operating at 50 Hz (80 m/s), good results have been obtained. Turbine drives should be designed to operate with a minimum tip speed of 90 m/s.

**References**

Fives Group in-line shredder installations are shown in Table 1.
Table 1—Installations of Fives Group in-line shredders.

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<th>Client</th>
<th>Country</th>
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**Performance**

Results were obtained from a random selection of factories, either sent to Fives Cail by the factory technicians or from the collection of results directly from site by Fives Group engineers, and the results collated into the graphs shown in Figure 7.
From these graphs, it can be seen that the absorbed power for the in-line shredder is normally around 40 kW.h/t fibre. Only three installations are operating in excess of 50 kW.h/t fibre; significantly all operate at less than 80% of their intended capacity and so it appears preferable to operate the machines and drives under load and close to their design capacities to prevent inefficiencies occurring. The drive split for the factories shown below is approximately 50/50 turbines and electric motors.

**Advantages of the in-line shredder**

- **One-stop cane preparation:** No pre-preparation is required.
- **Retro fitting:** A huge advantage with the in-line shredder is the ability to fit the shredder and carding drum into an existing carrier layout, (the shredders are supplied complete with all casings to match with the existing carrier sideplates). Normally, the installation can be achieved with a minimum of modification and incorporating most of the original equipment including carrier drives and drive positions, slats, etc (although the slats have to be operated in a ‘reversed’ direction to work successfully with the contra-rotating rotor). For factories that operate year-round, the shredder and carding drum can be positioned around existing knives and leveller equipment so that the new installation can be built and commissioned within two to three weeks.
- **Space:** Only 1 × carrier and 1 x conveyor are required to transport cane from the feed tables to No.1 mill.
- **Simplicity:** Fewer cane carriers mean there are significantly reduced costs in terms of material stocks and off crop maintenance for slats, drives, chain etc.
- **Installation costs:** In any project, in addition to the overall cost of the equipment, any civil works must also be considered. The in-line shredder cuts installation costs because it requires a very much smaller footprint regarding civil foundations, and a lower height requirement. The design requires a reduced quantity of machinery and with fewer drives.
• Versatility: In-line shredders will operate in almost all conditions, with washed or dry cane, in sandy areas and also in areas where rocks are a particular problem as the reverse rotation nature of the rotor means that rocks up to 300 mm diameter tend to be chipped into small pieces, thus protecting the mills.

• Long fibres: Because the shredder is processing cane that is not pre-knifed, the resulting cane fibres it produces are usually slightly longer, which tends to reduce mill slippage as the cane mat binds together better. Long fibres can also be advantageous to boiler operation.

• Increased extraction: Cane with a greater breakage of cells (i.e. more highly prepared) generally results in increased mill extraction, lower pol % bagasse figures and lower final bagasse humidity. Several suggestions have been made as to the increase in extraction possible. Moor (1974) suggests 0.045 units of extraction per 1% increase in preparation index; Edwards (1995) suggested a 0.1% increase in extraction per 1% increase in preparation index. Independent tests carried out at Tongaat Hulett in South Africa some years ago indicated an increase of 0.83% extraction for each 1% increase in preparation index within the range of 87% to 94%.

• The shredder rotor (and carrier width) can be increased later for higher capacities or phased expansions.

• Example case: At the Benito Juarez factory, cane preparation of preparation index approximately 80% was achieved using two cane knives and a light duty shredder. Factory results for this installation over a crop period showed a reduced extraction of 94.9% with an average imbibition rate of 26.6% on cane. After the shredder installation and with no other significant changes to the extraction plant, the reduced extraction increased to 95.85% with an imbibition rate of 21.4% on cane. These results would suggest an increase in extraction of approximately 0.1% per 1% increase in preparation index. Similarly, pol % bagasse reduced from 2.3% to 1.9%. However, these improved figures should be taken as an indication only as to what might be possible rather than an expectation of results.

• Energy savings: For the examples shown earlier in the text, the installed cane preparation powers as advised by Group Fives are as follows:

| In-line shredder | = 3180 kW |
| Cane knives + gravity shredder | = in-line shredder + 33% = 4230 kW |
| Cane knife + preparator + gravity shredder | = in-line shredder + 53% = 4860 kW |

The figures show that significant savings can be made regarding energy usage, allowing increased exportation to the grid where possible. For factories where energy savings are preferential to extraction, it is worth noting that a shredder can increase the overall performance by approximately the same amount as an extra mill; therefore, one existing mill could possibly be removed or bypassed, thus further increasing potential energy exportation.

Note: The figures above are a general indication of installed power only. In some areas, it is possible to install slightly lower installed power than in others. The relative percentage savings of the in-line shredder, both in terms of installed and absorbed power usually, however, remain.

• Reduced maintenance and downtime: To completely change the in-line shredder hammers takes approximately two hours and normally there is no more work required during the crop other than general adjustments. Hammer changes usually
take place at either one week or two week intervals during scheduled maintenance stops. Some factories that do not have scheduled stops change only half the hammers at any one time thus allowing them to complete the task very quickly (1 to 1.5 hours). This operation is completed during unscheduled stops (general breakdowns, process house full etc), so hammer changes do not require any specific down-time. Also, fewer hammers and knives (no cane knives and fewer hammers than a gravity shredder, 144 instead of 180 on an 2135 mm, eight-row shredder) means fewer weld repair materials, reduced man hours in terms of both repair and replacement, and reduced stock levels of equipment

- Milling operation: The addition of a carding drum and an in-line shredder will give a very consistent rate of cane feed, which improves the consistency of the whole milling operation, generally resulting in higher average milling performances.

- Mill protection: No magnet is required before the shredder, but a magnet is always recommended between the shredder and 1st mill to remove any ferrous materials and thus protect the mill. Therefore, No.1 mill is protected from both ferrous materials and rocks, reducing tooth breakage.

Disadvantages
- Individual installed drive power for the shredder rotor is generally higher than for a gravity shredder.
- A slat carrier is normally recommended for this type of shredder.

Conclusion

Fives Group manufactures and supplies almost all different types of cane preparation equipment; cane knives, cane preparators and both main types of heavy duty shredder, (the Fives Cail in-line design and the Fives Fletcher/Tongaat Hulett gravity design). Therefore, the company has no particular bias to any one type of equipment over another and so a balanced overview can be assured. For either new installations or for upgrading purposes, calculating the operational and financial advantages as well as the payback period is of utmost importance and so some or all of the following arguments might be considered:

- Increased co-generation potential
- Lower overall installed power
- Reduced routine and end-of-crop maintenance
- Reduction in off-crop oil consumption due to increased bagasse stocks
- Reduced civils and installation costs
- Reduced down-time (due to simplified installation)
- Reduction in man-hours and materials for refurbishing hammers and knives

It can be seen from the preceding arguments that for the majority of new installations and upgrades, there are genuine advantages to be gained from installing an in-line shredder, in terms of energy savings, installation and civil costs, maintenance savings and particularly co-generation benefits that will allow factories to operate at a higher level of efficiency than might previously have been possible.

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PRÉPARATION DE LA CANNE À SUCRE—TECHNOLOGIE OPTIMISÉE

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MOTS-CLEFS: Shredder, en Ligne, Préparation, Cannes

Résumé

Fives Cail a développé et amélioré sa technologie de préparation de canne à sucre pour répondre aux demandes des sucreries et usines d'éthanol qui veulent moderniser ou construire de nouvelles usines. Les principales préoccupations sont l'investissement, les performances, l’énergie et les opérations. Fives Cail a installé plus de 30 shredders en ligne, en Afrique, Asie et dans les Amériques. On a continuellement amélioré et développé la conception afin d'élargir la gamme jusqu'à une capacité de 825 tonnes canne heure, tout en simplifiant les conceptions d'alimentation, du tambour, du rotor, des marteaux et de l’enclume, tout en augmentant la capacité pour une largeur de transporteur donnée. La technologie shredder en ligne se compose de deux éléments principaux: une égalisation du niveau des cannes et l'assemblage du shredder, qui permet une installation très simple qui peut être soit intégrée dans un système existant ou installée dans une sucrerie neuve. Sa construction est modulaire avec un faible encombrement. Le shredder en ligne peut traiter la canne entière, des tronçons ou n'importe quelle combinaison des deux; il traite aussi la canne lavée et des cannes contenant une grande quantité de sable ou de roches. Tous les résultats présentés ont été obtenus directement des usines, soit par des canaux officiels, soit à partir des visites par le personnel du groupe Fives. Les résultats recueillis en dehors du laboratoire sont toujours moins certains ; toutefois, ils tendent à montrer des chiffres assez cohérents. Il peut donc être conclu qu'après plusieurs années de développements et d'améliorations, la recherche et les résultats montrent plusieurs avantages, directs et indirectes, avec l’installation du shredder en ligne dans une usine. Ces avantages comprennent des frais d'installation et des coûts de maintenance réduits et moins d’énergie, compare aux équipements de préparation plus conventionnels.
PREPARACIÓN DE CAÑA—TECNOLÓGIA OPTIMIZADA

Por

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PALABRAS CLAVE: Desfibradora, en línea, Preparación, Caña.

Resumen

FIVES CAIL ha desarrollado y mejorado su tecnología de preparación de caña para satisfacer los requerimientos de fábricas modernas de azúcar y etanol que buscan mejorar las fábricas o construir nuevas, siendo las mayores preocupaciones la inversión, desempeño, energía y operación. Fives Cail tiene a la fecha más de 30 desfibradoras en línea instaladas en África, Asia y las Américas, y ha mejorado y desarrollado continuamente el diseño para extender el rango de operación hasta una capacidad de 825 toneladas de caña por hora simplificando al mismo tiempo los diseños originales del tambor alimentador, rotor, martillos y yunque e incrementando la capacidad para un ancho de conductor determinado. La tecnología de la desfibradora en línea consiste de dos piezas principales de equipo: un nivelador de caña (o tambor peinador) y el conjunto de la desfibradora lo que permite una instalación simple y descomplicada que puede ser incorporada a un conductor existente o instalada sobre uno nuevo. Su construcción es modular con pocos requerimientos de espacio. La desfibradora en línea procesa caña entera o caña trozada o cualquier combinación de las dos, y puede operar en todas las condiciones posibles incluyendo la preparación de caña lavada o que contenga cantidades importantes de arena o piedras. Todos los resultados presentados han sido obtenidos directamente de las fábricas, bien a través de canales oficiales o a partir de visitas de personal de Fives Group. Como sucede con todos los datos obtenidos bajo condiciones fabriles y no de laboratorio deben suponerse algunas aproximaciones; sin embargo tienden a mostrar cifras bastante consistentes. Por lo tanto se puede concluir que después de varios años de continuo mejoramiento y desarrollo, la investigación y los resultados muestran que hay varios beneficios genuinos, tanto directos como indirectos, que pueden ser obtenidos incorporando la tecnología de desfibrado en línea en una fábrica para mejorar la preparación de caña. Los beneficios respecto a equipo más convencional se observan en términos de costos reducidos de instalación, menores costos de mantenimiento y menores consumos de potencia.
SUGAR-MILL COUPLING DEVELOPMENTS
SINCE 1987

By

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KEYWORDS: Coupling, Mill, Rope.

Abstract

Since the installation of the first Eurogear patented ‘rope’ coupling at the Umfolozi (South Africa) factory in 1987, the design has undergone numerous developments with respect to the materials of construction and the method of fixing to shafts. The material of construction of the main coupling components has been changed from cast steel grade A3 to fabricated steel grade 300WA and cast steel grade A4 to reduce its cost. Because of fatigue problems caused by excessive misalignment, steel wire ropes have been replaced by two new types of flexible members: polyester slings and the link plates with spherical plain bearings. The coupling hub to be connected to the shaft square has been significantly redesigned to simplify installation and to ensure a more even distribution of stress, even on damaged shafts. Shear pins have been introduced to provide a mechanical torque limitation system to protect the coupling, shaft and gearbox components. With all the developments over the last 24 years, the rope coupling is now a mature product and can provide enormous benefits to consumers.

Introduction

Since the installation of the first Eurogear patented ‘rope’ coupling at the Umfolozi (South Africa) factory in 1987 (Tosio, 1992), the design has undergone numerous developments with respect to the materials of construction and the method of fixing to shafts.

The paper discusses these developments and the reasons behind them, and also outlines new design options.

Background

Under misaligned conditions (which is nearly all the time), traditional ‘tail-bar’ couplings have the following detractions:

- They generate thrust between the mill and final-drive gearbox, resulting in wear to mill components, and gearbox bearing failures.
- In the event of a transverse mill shaft break, the gearbox can be severely damaged by the resulting thrust generated.
- They apply bending moments to the gear shaft that misalign the gear teeth because of bearing clearances, resulting in premature deterioration and failure.
- They are inefficient, and the power loss can affect mill performance if the available power is marginal.
- They require regular lubrication during operations, significant repair costs to shaft squares in the off-crop, and sometimes even cause shaft breakages.

Rope couplings

The ‘rope’ coupling, as it became known, was designed in 1986 to eliminate all of the undesirable effects of tail-bar couplings.

The SWR (Steel-Wire-Rope) coupling is shown in Figure 1.
Fig. 1—The SWR coupling.

The ropes connect the driving and driven yokes in a plane normal to the shaft axes via a floating strut that bends the ropes into two parallel pairs of flexible members roughly at right angles to one another.

Considered in static mode, the pair of near-horizontal ropes can absorb vertical misalignment, while the near-vertical pair of ropes can absorb horizontal misalignment. In addition, any axial movement can be absorbed by all the ropes flexing sideways.

The coupling can absorb any misalignment that may be required in driving a sugar mill, without causing any ill-effects to the mill or gearing.

**Coupling developments**

**Introductory remarks**

Over the years, numerous changes have been made to the design, all in the interests of improving the product.

**Materials of construction**

The yokes of the first 1987 coupling were made of cast steel, grade A3. This material proved to be very good, but expensive, and so other materials of construction were investigated.

Local foundries strongly advocated the use of SG iron, also known as ductile iron. The grade selected, for strength reasons, was SG60. This material worked well for about seven years, but costly failures occurred.

The first failure was caused by a severely out-of-square shaft that caused contact on only two points in the bore that resulted in extreme stresses in the material. The second failure was a casting failure caused by casting the yoke with the hub up. This process led to very slow cooling of the hub section that resulted in carbide separation and very brittle properties.

The material failures led to a re-think and, since then, all couplings have either been fabricated in mild steel grade 300WA of 280 MPa minimum yield strength, or cast steel grade A4, with minimum yield strength of 320 MPa.

**Flexible elements**

The flexible elements that provide the misalignment capability of the coupling have seen a much more radical change. The steel wire ropes proved perfectly suitable for driving mills that are
well aligned to the final drive gearing and well operated (as they should be). In these circumstances, the normal maximum misalignment is less than 20 mm.

In 1997, one installation in South Africa and numerous installations in Brazil suffered premature rope failure. Although lift-indicators showed that misalignment was minimal, this assessment was incorrect. Subsequent irrefutable tests proved that the actual misalignment was, in all of these cases, in excess of 35 mm. As a result, the steel wire ropes had to flex back and forth more than 70 mm every revolution. This movement proved far too much for the steel-wire ropes, especially in Brazil where milling speeds are typically 7 r/min, and alternative designs had to be sought to cope with this type of problem.

Two other flexible members have subsequently replaced the steel wire ropes, namely polyester slings (Figure 2) and link plates fitted with maintenance-free spherical plain bearings (Figure 3).

Fig. 2—Rope coupling with polyester slings.

Fig. 3—Rope coupling with link plates fitted with spherical plain bearings.
The polyester slings (Figure 4) are proving very reliable, although attention has to be paid to the following to ensure they work as designed:

- It is essential that the slings are all the same length so they share the load equally.
- The slings have to be manufactured very uniformly in cross-section so that all the strands share the load equally.
- Frequent destructive tests should be carried out on slings to be sure design service factors are maintained, and that fabricators are not cutting corners.

![Polyester Sling Undergoing Destructive Test](image)

Spherical plain bearings have not achieved the life predicted by the suppliers, but there are numerous reasons for this, the main causes being abuse during operations and poor storage practices during the off-crop.

**Fixing hubs to shafts**

The biggest challenge in the first 10 years of making couplings was to design a good system of fitting yoke-hubs onto shaft-squares that were never, in fact, square. From very early days, all engineers have been advised (in our data sheet that they complete) to restore shafts to original dimensions, and make sure they are square. A typical, non-square, shaft square is shown in Figure 5.

![An Un-Repaired Shaft Square](image)

The first (1987) coupling was fitted to the shaft square with keys. This design required excessive fitting time because of poor machining, so a better system was needed.
Subsequently, cast SG iron couplings were profile cast and machined to slide onto the squares and were fixed in position using reversing screws. This method worked reasonably well until a seriously out-of-square shaft caused failure due to uneven loading and high stress-generation. The practice was subsequently discontinued.

Hubs were then fitted onto shafts using heavy-duty shrink-discs (Figure 6). This method works very well if squares are accurately machined and square, so is good for new installations such as at the Komati factory in South Africa in 1994. This method also requires excessive fitting time and was not deemed suitable for retro-fit installations. Lighter shrink-discs (quicker to fit) were tried but also required close shaft-tolerances. Old shaft-squares are never properly repaired or restored to original dimensions, so this system was also discontinued.

Fig. 6—Shrink-discs used to fit couplings to shafts.

The final solution to fitting problems was introduced in 1996 when a new profile bore design was introduced (Figure 7), and it has been so successful there is no intention to change it.

Fig. 7—Hub fitting on shaft.
This strange-looking slide-on design has a cast or profile-cut bore with very large corner radii, which minimises stresses. In taking load, the bore makes contact close to, but not quite on, all four corners of the square. Note each bore-profile has to be specially designed to fit in the optimum position. Initially the arc-to-flat contact is only line contact, but this line crushes immediately load is applied until the flattened area is so large that the stress falls below the yield point of the hub material, which is always softer than the shaft.

This design caters to small shaft-square dimensional inaccuracies, and always ensures four-corner load-sharing. It also optimises the hub thickness and therefore minimises the cost of manufacture. It can distort slightly should this be necessary, thereby ensuring that all corners are equally loaded. The hubs are retained on the outside ends of the squares by sets of ‘Sandwich’ plates (Figure 8).

![Figure 8 — Hub fitting on shaft.](image)

**Torque limitation**

For the past five years, all designs have had a torque limitation option in the form of shear pins to protect the mill and (more importantly) gearbox from damage should a pinion break or a large object enter the mill and cause a stall. For design purposes, a break torque of 150% of estimated normal driving torque has been used.

The shear-pins, shown in Figure 9, are always fitted to a pair of flanges integral with the gear-side hub or tube-to-yoke connection. The flanges are fitted with hardened bushes to support the shear pins without themselves being damaged.

In the event of the shear pins failing, the coupling stops turning, providing a very visible indication of a problem. The cause of the failure can then be investigated and the shear pins can be replaced. Shear pin replacement takes only a few minutes.

**New Designs**

The following new designs are available:

1. Eurogear’s MKI ‘Link’ coupling, which is of similar construction to the polyester-sling coupling, but which utilises link-plates containing spherical plain bearings to impart the flexibility required.
2. Eurogear’s MK VI ‘multi-link’ coupling, that utilises spherical plain bearings to give it misalignment properties. This coupling is similar to a universal coupling, but has the added advantage of end collapsibility. It was designed for customers who did not like the large swing of the other designs.
Conclusions

Since its introduction in 1987, the rope coupling has undergone significant further development.

The material of construction of the main coupling components has been changed from cast steel grade A3 to fabricated steel grade 300WA or cast steel grade A4 to reduce its cost.

Because of fatigue problems caused by excessive misalignment, steel wire ropes have been replaced by two new types of flexible members: polyester slings and the link plates with spherical plain bearings.

The coupling hub to be connected to the shaft square has been significantly redesigned to simplify installation and to ensure a more even distribution of stress, even on damaged shafts.

Shear pins have been introduced to provide a mechanical torque limitation system to protect the coupling, shaft and gearbox components.

With all the developments over the last 24 years, the rope coupling is now a mature product and can provide enormous benefits to consumers.

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DEVELOPMENTS DES MANCHONS
POUR LES MOULINS DEPUIS 1987

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MOTS CLEFS: Manchons, Moulin, Corde.

Résumé
Depuis l'installation de la première 'corde' brevetée Eurogear comme manchons à l'usine de Umfolozi (Afrique du Sud) en 1987, les matériaux de construction et la méthode de fixation d'arbres ont subi de nombreux développements. Le matériau de construction des composants principaux est maintenant l’acier 300WA et l’acier grade A4, au lieu de la fonte A3, pour réduire les frais. En raison de problèmes de fatigue, causés par un mauvais alignement, les câbles d'acier ont été remplacés par deux nouveaux types de membres flexibles: écharpes polyesters et les plaques de lien par des rotules. On a simplifié l'installation du manchon pour assurer une répartition plus uniforme du stress, même sur les arbres endommagés. Des mesures ont été introduites pour limiter le couple mécanique afin de protéger le manchon, l’arbre et la boîte de vitesse. Avec tous les développements au cours des 24 dernières années, le manchon a corde est maintenant un produit bien établi et peut fournir des avantages sérieux pour les consommateurs.

DESARROLLOS DE ACOPELES PARA MOLINOS DE CAÑA DESDE 1987

Por

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PALABRAS CLAVE: Acople, Molino, Cable.

Resumen
Desde la instalación del primer acople 'de cable' patentado de Eurogear en el ingenio Umfolozi (Sudáfrica) en 1987, el diseño ha tenido numerosos desarrollos respecto a los materiales de construcción y el método de fijación a los ejes. El material de construcción de los componentes principales del acople ha sido cambiado del acero fundido grado A3 a acero laminado grado 300WA y acero fundido grado A4 para reducir su costo. Debido a problemas de fatiga causados por excesivos desalineamientos, los cables de acero han sido reemplazados por dos nuevos tipos de elementos flexibles: eslingas de poliéster y platinas de conexión con cojinetes planos tipo rótula. El cubo de acople que se conecta al cuadrante del eje ha sido significativamente rediseñado para simplificar la instalación y asegurar una distribución más pareja de esfuerzos aún en ejes deteriorados. Se han introducido pasadores de corte para proveer un sistema mecánico de limitación de torque para proteger el acople, el eje y componentes del reductor. Con todos los desarrollos durante los últimos 24 años, el acople de ‘cable’ es ahora un producto maduro y puede dar enormes beneficios a los usuarios.
THE EFFECT OF ADDED WATER TEMPERATURE ON MILLING TRAIN OPERATION AND PERFORMANCE

By

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KEYWORDS: Added Water, Imbibition, Maceration, Milling, Extraction.

Abstract

Four recent factory experiments have been conducted to provide information to determine an optimal added water temperature. The results were not completely conclusive but did provide some further insight into the effect of added water temperature. The effect of added water temperature on extraction has proven particularly difficult to measure. There is little doubt that bagasse is more compressible at higher temperature. Two experiments have shown that bagasse moisture content is lower at higher temperature. These effects are most likely related. Two experiments produced indirect evidence of an increase in extraction with higher added water temperature. With bagasse being more compressible, mill capacity is increased at higher temperature. The use of a heat exchanger to cool added water with mixed juice reduces heat loss and consequently reduces steam usage for primary heating of juice. Some of the lost heat may serve a useful purpose in increasing boiler efficiency, resulting in more efficient use of bagasse. Hotter added water does not appear to be a complete solution for mill hygiene since even the hottest added water investigated only provides sufficient benefit for the last one or two mills. There remains considerably more work to identify the optimal added water temperature. The main outstanding issues are the effect of added water temperature on extraction, the effect of hotter bagasse on boiler efficiency through moisture content or temperature and the impact of bagasse temperature on hygiene.

Introduction

According to Maxwell (1932), the optimal temperature for milling train added water has been debated since the nineteenth century (von Czernicky, 1899). Chen (1993) provided a comprehensive list of the arguments with benefits of high temperature being fuel economies, rupture of cells, evaporation from bagasse in transit, use of return condensate from evaporators and a gain in extraction, and disadvantages of high temperature being extraction of gums and impurities, poorer mill feeding and the facilitation of growth of micro-organisms that produce dextran.

Much of the data on which today’s understanding of the impact of added water temperature dates back many years. Maxwell (1932) questioned the validity of the results of von Czernicky (1899) since milling technology had changed in the intervening 30 years. Milling technology has continued to evolve, with innovations such as roll roughening, closed feed chutes and automatic control systems. There is a need to reassess conventional wisdom on the subject.

This paper reviews past work, presents recent work and presents a theory to explain the measured impacts.

Definitions

Throughout this paper, added water refers to water that is added to the milling train to aid the extraction process. Added water is usually applied before the final mill.
Most past work on the subject uses the terms *maceration* or *imbibition*. Clayton (1971) defines imbibition as *the process in which water or juice is applied to a bagasse to enhance the extraction of juice at the next mill*. This definition includes the above definition of added water but also includes juice added to mills before the final mill. Clayton (1971) indicates that the term maceration is used *loosely as an alternative to the term imbibition*.

**Review of past work**

**Fuel economy**

Fuel economy results from a boiler efficiency increase that can be achieved through burning bagasse of lower moisture content. Khainovsky (1929) reported reductions in bagasse moisture content from cold maceration (20°C to 30°C) to hot maceration (80°C to 90°C) processes.

**Rupture of cells**

Khainovsky (1929) reported that living cells were not ruptured and actively worked to increase their sucrose content. He found that, using cold imbibition, living cells could still be detected in final bagasse. The actual temperature at which living cells were killed was not measured but Khainovsky indicated it was about 60°C.

Ramaiah *et al.* (1979) stated that surface tension effects were responsible for sucrose being trapped in cells. Kumar and Agrawal (2000) stated that hot imbibition reduces surface tension effects, increasing extraction. No supporting evidence was presented.

**Evaporation from bagasse in transit**

Hotter added water results in hotter bagasse. While it is expected that hotter bagasse will result in greater evaporation, and hence lower moisture content, it is not believed that any such measurements have ever been published.

**Use of return condensates from evaporators**

Many factories use hot condensates from the evaporators for added water. Valdes *et al.* (1994) presented a study to maximise energy efficiency at different added water temperatures.

In some factories, maceration heaters are used to increase added water temperature. Doss (1986) recommends the addition of steam to imbibition in a process called steam aided imbibition. Other published reports discuss methods to reduce added water temperature. Nigam *et al.* (1990) discuss mixing hot condensate with cold water. Leal *et al.* (1986) and Castellat and Mendoza (1988), as reported by Valdes *et al.* (1994), along with Bhojaraj (1990) and Nandagopal (1991), indicate that using a heat exchanger with mixed juice as a cooling fluid is a more energy-efficient method to reduce added water temperature. Bhojaraj (1990) indicates this method can save 3% steam on cane.

**Extraction of sucrose**

Khainovsky (1929) reported reductions in bagasse pol content between the use of cold maceration (20°C to 30°C) and hot maceration (80°C to 90°C) processes. Khainovsky noted that hot bagasse was more compressible and indicated that this property was responsible for the improved performance.

From studying extraction results over several seasons, Gonzalez (1953) found no change in extraction after changing added water temperature from 77°C to 55°C.

Sugar Research Institute (1955) found an increase in total pol extraction by increasing added water temperature from 38°C to 77°C. The hot added water tests also involved the addition of steam into the mill boots, resulting in hotter bagasse at the intermediate mills and increased added water rate because of the condensed steam.

Haines and Hughes (1962) found an increase in pol extraction by increasing added water temperature from 26°C to 77°C.

Hugot (1986) reported that, of his four factories, one factory found an improvement in extraction with hot imbibition but the remaining three factories did not.
Ramasamy (1988) conducted factory and laboratory experiments to compare different imbibition temperatures and steam aided imbibition. He found that bagasse pol content was lower with higher temperature imbibition and attributed that lower pol content to sucrose inversion. He presented no evidence that sucrose inversion was the cause of the lower pol content (as opposed to, for example, the compressibility mechanism proposed by Khainovsky (1929).

**Extraction of impurities**

Honig (1953) carried out a factory experiment to investigate extraction of waxy matter. He carried out 10 pairs of tests with added water temperatures of 28°C and 85°C and concluded that there was no definite proof that added water temperature affected extraction of waxy matter.

Gonzalez (1953) found that sugar filterability was much poorer with an added water temperature of 77°C than with an added water temperature of 55°C. He concluded that poor filterability came from the rind of the cane and hypothesised that it was extraction of waxes that caused the problem.

Garcia and Saska (1992) conducted a laboratory study on the effect of imbibition temperature on the extraction of polysaccharides and lignins. No results were presented.

**Mill feeding**

Khainovsky (1929) reported that, for a milling train set for cold maceration, mill capacity (feeding) initially drops when hot maceration is first used. When optimal mill settings for hot maceration are determined, capacity returns to the cold maceration level.

Sugar Research Institute (1955) found that increasing the imbibition temperature by about 30°C to 77°C resulted in an increase in mill speed.

Haines and Hughes (1962) found that mill feeding became noticeably more difficult at imbibition temperatures above 82°C.

**Growth of micro-organisms**

Moroz (1963), referencing the work of Hucker and Pederson (1930), reported on the presence of micro-organisms in juice, most notably *Leuconostoc mesenteroides*, that are known to cause dextran. He indicated that the temperatures for optimal growth of these micro-organisms was 21°C to 25°C but that the micro-organisms can grow within the wider temperature range from 5°C to 45°C. Moroz recommended temperatures over 65°C for good hygiene.

**Factory experiments**

**Design**

This section summarises the results of four factory experiments undertaken by the author into the effect of added water that have been conducted recently (Table 1).

<table>
<thead>
<tr>
<th>Factory</th>
<th>Year</th>
<th>Number of tests</th>
<th>Temperatures (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isis, Australia</td>
<td>2005</td>
<td>16</td>
<td>60, 98</td>
</tr>
<tr>
<td>Ledesma, Argentina</td>
<td>2006</td>
<td>4</td>
<td>57, 77</td>
</tr>
<tr>
<td>Plane Creek, Australia</td>
<td>2007</td>
<td>18</td>
<td>56, 75, 92</td>
</tr>
<tr>
<td>Macknade, Australia</td>
<td>2008</td>
<td>26</td>
<td>61, 92</td>
</tr>
</tbody>
</table>

At Isis and Ledesma, the cooler temperature was achieved through the use of a mixed juice heater, similar to those described by Leal *et al.* (1986), Castellat and Mendoza (1988), Bhojaraj (1990) and Nandagopal (1991).

At Plane Creek and Macknade, the cooler temperature was achieved by mixing the hot condensate with cool injection water, similar to the process described by Nigam *et al.* (1990).
Results

Expressed juice temperature

Figure 1 presents the average expressed juice temperatures for the three factories where measurements were made. Even though the added water temperature at each factory differed by over 30°C, the temperature of the mill 5 expressed juice differed by no more than 22°C, and the temperature of the mill 2 expressed juice differed by no more than 6°C.

![Graph showing expressed juice temperatures](image)

A horizontal line has been drawn across the graph at 65°C, the temperature recommended by Moroz (1963) for good hygiene. The measurements show that, to achieve a juice temperature over 65°C on the final mill, the added water temperature needs to be above 75°C. A juice temperature over 65°C on the second last mill was only achieved with an added water temperature above 92°C. If a temperature above 65°C is to be achieved along the milling train, additional heating is required in the intermediate mills.

Delivery nip compaction

Figure 2 presents the average increase in delivery nip compaction from the tests with the coldest added water temperature to the tests with the hottest added water temperature. Analyses of variance showed that the delivery nip compaction difference for mill 4 and mill 5 at Isis and all mills at Macknade was statistically significant.

![Graph showing increase in delivery nip compaction](image)
The difference in delivery nip compaction has an increasing trend from mill 1 to the final mill in all cases, although the mill 4 result from Plane Creek is quite different. Figure 3 plots the increase in delivery nip compaction against the increase in juice temperature for the Macknade results and shows an almost linear trend. These results support the conclusion of Khainovsky (1929) that bagasse is more compressible at higher temperature.

![Graph showing the relationship between delivery nip compaction difference and juice temperature difference](image)

**Fig. 3—Increase in delivery nip compaction as a function of the increase in juice temperature for the Macknade tests.**

**Total pol extraction and final bagasse moisture content**

Table 2 presents the average increase in total pol extraction and average decrease in final bagasse moisture content from the tests with the coldest added water temperature to the tests with the hottest added water temperature. Analyses of variance revealed that the extraction difference at Plane Creek and the moisture content differences at Isis and Macknade were statistically significant.

**Table 2—Summary of average increase in total pol extraction and final bagasse moisture content from coldest to hottest added water.**

<table>
<thead>
<tr>
<th>Factory</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Extraction</td>
</tr>
<tr>
<td>Isis</td>
<td>0.0</td>
</tr>
<tr>
<td>Ledesma</td>
<td>−0.2</td>
</tr>
<tr>
<td>Plane Creek</td>
<td>−0.8</td>
</tr>
<tr>
<td>Macknade</td>
<td>−0.1</td>
</tr>
</tbody>
</table>

The Isis and Macknade bagasse moisture content results were both statistically significant and showed a reduction in bagasse moisture content with an increase in added water temperature, in line with the results of Khainovsky (1929). The Ledesma and Plane Creek results showed the opposite trend but were not statistically significant. Consequently, the Isis and Macknade results are considered a more reliable indicator of the true trend. These results support the delivery nip compaction results, since higher delivery nip compaction is expected to result in lower bagasse moisture content.

The delivery nip compaction and bagasse moisture content results support the argument that an increase in added water temperature will cause an increase in extraction. The Isis and Macknade
results, where statistically significant bagasse moisture results were obtained, do not show this trend. The Plane Creek extraction results, which were statistically significant, show the opposite trend.

At Isis Mill, the cooler added water temperature caused a large increase in torque, beyond the ability of the control system to compensate. To limit the torque, the average added water rate was increased during the cool added water tests from 307 % fibre to 362 % fibre, a statistically significant difference. The increase in added water rate can be expected to increase extraction. Since no increase in extraction was observed during the cool added water tests, it can be concluded that the increase in extraction due to the higher added water rate was counteracted by a decrease in extraction due to the cooler added water temperature.

At Macknade Mill, although the order of tests was randomised, the ratio of pol to fibre in cane was higher during the cool added water tests (1.06 compared to 1.02), a statistically significant difference. Extraction can be expected to be higher when the pol to fibre ratio in cane is higher. Since no increase in extraction was observed during the cool added water tests, it can be concluded that the increase in extraction due to the higher pol to fibre ratio was counteracted by a decrease in extraction due to the cooler added water temperature.

While there is no direct evidence to show that an increase in added water temperature causes an increase in extraction, there is some indirect evidence that such a trend exists. These results support those of Khainovsky (1929), Sugar Research Institute (1955), Haines and Hughes (1962), Hugot (1986) and Ramasamy (1988). There is also, unfortunately, some contradictory evidence such as the Plane Creek Mill results. Weighing the evidence, the author believes that a small increase in extraction with an increase in added water temperature does occur but that it is difficult to measure. This increase is believed to be about 0.2 units of extraction, for an increase in added water temperature from 60°C to above 90°C. An analysis of the Macknade Mill results indicated a standard error in the extraction measurement of 0.6 units of extraction, at least partly explaining why an extraction difference is hard to detect.

**Feed chute exit compaction**

Figure 4 presents the average increase in feed chute exit compaction from the tests with the coldest added water temperature to the tests with the hottest added water temperature. Analyses of variance revealed that the feed chute exit compaction difference for mill 4 at Isis and mill 1, mill 3, mill 4 and mill 5 at Macknade were statistically significant.
The Macknade results do show an increasing trend of feed chute exit compaction with added water temperature, like the delivery nip compaction trend. There is also some evidence of a trend in the Isis and Plane Creek results, although there is some contradictory data. Figure 5 plots the increase in feed chute exit compaction against the increase in juice temperature for the Macknade results and shows, as for the delivery nip compaction results, an almost linear trend. These results provide further evidence that bagasse is more compressible at higher added water temperature.

![Figure 5](image_url)

**Fig. 5—Increase in feed chute exit compaction as a function of the increase in juice temperature for the Macknade tests.**

The feed chute exit compaction is a strong indicator of mill feeding and mill capacity and, unlike mill speed, is independent of fibre rate and mill settings. Higher feed chute exit compaction indicates better mill feeding and correlates with lower mill speed. The feed chute exit compaction at the final mill at Macknade increased 7% by increasing the added water temperature from 61°C to 92°C.

**Energy efficiency**

As part of the experiment at Isis, where a mixed juice heater was used to cool the added water, the heating effect on mixed juice was also examined. By cooling the added water from 98°C to 60°C, the mixed juice temperature increased from 42°C to 54°C. As a result, the steam flow to the primary heaters reduced from 12.5 % cane to 10.8 % cane.

The fact that less steam was required for the cool added water case indicates that it is a more energy efficient option. In the cool added water case, some heat is transferred from the added water directly into mixed juice. In the hot added water case, heat is transferred from the added water to the bagasse and from the bagasse into mixed juice, with some heat lost either in vapour along the milling train and in bagasse. The hotter bagasse may also translate into an energy saving due to improved boiler efficiency, either by greater evaporation to reduce bagasse moisture content or by feeding hotter bagasse into the boiler. The size of this benefit has not been measured or estimated but may at least partly offset the higher juice heating requirement.

**Conclusions**

The effect of added water temperature on extraction has proven difficult to measure. There is little doubt that bagasse is more compressible at higher temperature. Two experiments have shown that bagasse moisture content is lower at higher temperature (1 to 2 units as added water
temperature increased from 60°C to 90°C). These effects are most likely related. Two experiments produced indirect evidence of an increase in extraction with higher added water temperature (predicted to be about 0.2 units). One experiment provided direct evidence of a decrease in extraction with increasing added water temperature. This result is inconsistent with the remaining evidence but cannot be discounted. More research is required to better understand this extraction effect.

With bagasse being more compressible, mill capacity is increased at higher temperature (7% for the final mill at one factory, where bagasse temperature increased from 53°C to 75°C).

The use of a heat exchanger to cool added water with mixed juice reduces heat loss and consequently reduces steam usage for primary heating of juice.

Some of the lost heat may serve a useful purpose in increasing boiler efficiency resulting in more efficient use of bagasse, but this effect has not been measured.

Hotter added water does not appear to be a complete solution for mill hygiene. If bagasse needs to be heated above 65°C, even the hottest added water temperatures only provide sufficient benefit for the last one or two mills.

There remains considerably more work to identify the optimal added water temperature. The main outstanding issues are the effect of added water temperature on extraction, the effect of hotter bagasse on boiler efficiency through moisture content or temperature and the impact of bagasse temperature on hygiene.

Acknowledgements

The financial support of the Sugar Research and Development Corporation, Ledesma s.a.a.i. and CSR Ltd is acknowledged. Isis, Ledesma, Plane Creek and Macknade staff, in particular Mr David Pike, Mr Claudio Zapatero, Mr Paul Benecke and Mr Mick Conroy, provided considerable assistance in conducting the experiments. Mr Neil McKenzie and Dr Floren Plaza of QUT assisted in the conduct and analysis of experimental results.

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L'EFFET DE LA TEMPÉRATURE D'EAU AJOUTÉE SUR L'OPERATION ET LA PERFORMANCE DES MOULINS

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MOTS-CLEFS: Ajoutés à l'Eau, Imbibition, Macération, Moulins, Extraction.

Résumé

QUATRE expériences récentes, faites en usines, ont été menées pour déterminer une température optimale de l'eau ajoutée. Les résultats n'ont pas été totalement concluantes mais ont fourni des détails supplémentaires sur l'effet de la température d'eau ajoutée. L'effet de la température d'eau ajoutée sur l'extraction s'est avéré particulièrement difficile à mesurer. Il y a peu de doute que la bagasse est plus compressible aux températures plus élevées. Deux expériences ont montré que l'humidité de la bagasse est inférieure à la température plus élevée. Ces effets sont probablement
liées. Deux expériences montrent indirectement une augmentation de l'extraction par la température d'eau ajoutée plus élevée. La bagasse plus compressible augmente la capacité. L'utilisation d'un échangeur de chaleur pour refroidir l'eau ajoutée réduit les pertes de chaleur et par conséquent, réduit l'utilisation de la vapeur pour le chauffage principal du jus. Cela peut augmenter l'efficacité des chaudières, ce qui se traduit par une utilisation plus efficace de la bagasse. L'eau chaude ne semble pas être une solution complète pour l'hygiène du train de moulins étant donné que même l'eau la plus chaude a avantagée seulement le dernier ou les deux derniers moulin. Il faut beaucoup plus de travail pour identifier la température optimale d'eau ajoutée. Les principales questions restées sans réponses sont l'effet de la température d'eau ajoutée sur l'extraction, l'effet d’une bagasse plus chaude sur le rendement des chaudières à travers la teneur en humidité ou la température, et l'impact de la température de la bagasse sur l'hygiène.

EL EFECTO DE LA TEMPERATURA DEL AGUA ADICIONADA EN LA OPERACIÓN Y DESEMPEÑO DE UN TREN DE MOLIENDA

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PALABRAS CLAVE: Agua Adicionada, Imbibición, Maceración, Molienda, Extracción.

Resumen

Se efectuaron recientemente cuatro experimentos en fábrica para suministrar información en la búsqueda de la temperatura óptima del agua adicionada. Los resultados no fueron completamente concluyentes pero entregaron una visión adicional sobre el efecto de la temperatura del agua adicionada. Históricamente, este efecto ha sido particularmente difícil de medir. Hay pocas dudas en cuanto a que el bagazo sea más compresible a altas temperaturas. Dos experimentos mostraron que la humedad del bagazo es menor a temperaturas altas. Estos efectos están probablemente bien relacionados. Dos experimentos produjeron evidencia indirecta de un incremento en la extracción con la mayor temperatura del agua adicionada. Siendo el bagazo más compresible la capacidad de molienda se incrementa a altas temperaturas. El uso de un intercambiador de calor para enfriar el agua adicionada con jugo diluido reduce las pérdidas de calor y consecuentemente reduce el consumo de vapor para el calentamiento primario del jugo. Algo del calor perdido puede ser útil para incrementar la eficiencia de calderas resultando en un uso más eficiente del bagazo. El agua adicionada más caliente no parece ser una solución completa para la higiene del tándem dado que solo representa un beneficio, en el mejor de los casos, para el último o los dos últimos molinos. Todavía se requiere considerable trabajo para identificar la temperatura óptima para el agua adicionada. Los aspectos más sobresalientes son el efecto de la temperatura del agua en la extracción, el efecto de un bagazo más caliente en la eficiencia de caldera, a través del contenido de humedad o la temperatura y el impacto de la temperatura del bagazo en la higiene del tándem.
IMPROVEMENTS TO A SUGARCANE ROAD TRANSPORTATION SYSTEM

By

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KEYWORDS: Cane transport, Fuel Consumption, FEA Modelling.

Abstract
AMONG the costs of the whole cane sugar and ethanol production system, the activities covered by harvesting (manual and mechanical), road transportation and cane unloading are the most expensive category of operations. A comprehensive study of the cane transport system, that covers topics from system logistics to cane bin design, is being undertaken for the Colombian sugar industry. Models for predicting fuel consumption have been developed and tested using techniques like GPS, pull load and direct fuel flow measurements for the complete operational cycles. Sensitivity trials have also been performed to analyse the influence of bin weight on fuel consumption in the complete cycle and FEA modelling has been applied to the design and construction of new equipment. Results show that reductions of 5% of fuel costs are achieved with the 10% structural weight reduction achieved.

Introduction
Cane supply management represents a real challenge for achieving overall efficiencies in the production processes to obtain sugar, ethanol and exportable electricity.

The huge variety of resources and activities involved simultaneously in field, harvesting (batch processes) and factory (mostly continuous processes) requires modern techniques and tools with a systems approach to assess and influence the processes continuously.

The risk of losing competitiveness because of high production costs, low prices of final products and devaluation of the national currency are threats for Colombia’s sugar industry and it is necessary to look for new and better production systems, especially in the harvesting, transport and delivery of the cane.

These operations constitute, on average, one third of the sugar production costs of which transport is 37% of this figure (Ramirez, 2006).

Currently 80% of the cane is cut manually but some individual mills are approaching 60% mechanical harvesting.

Cane is transported by road using three different size bins with 12, 20 and 30 tonnes capacity of chopped cane.

The 12 and 20 tonne bins are loaded directly with chopped cane from the harvester or from the loader in the case of manual harvesting.

Figure 1 show a typical train composed of four 20 tonne wagons.

At the mill yard, cane is unloaded by lifting cranes tipping on to feeding tables from where the cane is fed controlled to the main carrier. Severe damage and compaction happens in the fields, particularly in the rainy seasons, so the industry is returning to the use of tipping wagons of 7.5 and 10 tonne nominal capacity.

Cenicaña is currently running a research project on cane supply operations, aiming to reduce production costs by improving the complete cane supply system. The project includes field design,
private road circuits for neighbouring factories, logistics strengthening and equipment design, as well as redesigning together with equipment suppliers.

Logistic analysis

A simulation computer program based on Excel and linked with Crystal Ball® has been developed for the analysis of complete cane supply operations. It covers resources configuration and operational strategies evaluation, applying stochastic simulation. Statistical variation of input variables and equations were defined with real time information taken from a pilot mill and also from historical data. Cycle time, number of cycles, number of hauling units and the different logistic indices are obtained as program output.

A logistics benchmark was established and a first opportunity for improvement was found in the mill yard. Some results on improvement of spent time in the mill yard by transport equipment are presented in Figure 2. As a consequence of this improvement, equipment availability was improved.

![Typical train composed of four 20 ton wagons.](image1)

**Fig. 1**—Typical train composed of four 20 ton wagons.

![Mill yard time before and after applying logistics improvements.](image2)

**Fig. 2**—Mill yard time before and after applying logistics improvements.
So far it has been possible to reduce up to 15% of resources in the pilot mill with better coordination in cane loading, transport and unloading. Quality and opportunity of factory and harvesting personnel communication is a key logistic factor (Amú et al., 2007).

**Transport equipment analysis**

Recently, Santarossa et al. (2007), using finite element analysis, developed a new bin design (10 tonne railroad wagon) and achieved important structural weight savings while keeping good strength performance.

From the inventory of wagons in the Colombian industry, the 12 tonne type is the most extensively used unit, comprising 40.03% of the total industry fleet. It was chosen for structural integrity and maintenance costs analysis.

The most maintenance demanding zones in the chassis and bin were determined and compared with Finite Elements Analysis (FEA) predictions. A close agreement between predicted critical points and reported failure zones was found. Upper corners on the unloading side of the bin and the transition between the chassis central member and the neck were found to be the highest stressed zones. Figure 3 shows FEA outputs for the bin and chassis during cane unloading.

![Stresses during cane unloading a) bin b) chassis](image-url)
In order to calibrate the FEA models for the bin and chassis, experimental stress analysis was performed using strain gauges bonded at critical points in the wagon structure (Figure 4).

Stress levels were determined during field loading, while travelling on paved and unpaved roads and while unloading at the feeding table. A static loaded wagon condition was established as Service Factor = 1 and different factors were determined for other conditions (Table 1).

The critical condition for the loaded wagon chassis occurred when travelling in the field (factor 2.92). For the bin, the worst scenario was the unloading operation (factor 2.41). For off-road travel, a bigger factor was found than the factor of 1.8 reported by Moreno et al. (2000). Table 2 shows a comparison between FEA predicted stresses and experimental measurements.

**Table 1**—Service factors for cane transport. Static and level loaded wagon considered as a reference.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Chassis</th>
<th>Bin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empty wagon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unpaved road</td>
<td>1.46</td>
<td>0.69</td>
</tr>
<tr>
<td>Unpaved road-turning</td>
<td>1.76</td>
<td>0.7</td>
</tr>
<tr>
<td>Loading and movement in the field</td>
<td>2.92</td>
<td>2.17</td>
</tr>
<tr>
<td>Loaded wagon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unpaved road</td>
<td>2.04</td>
<td>1.3</td>
</tr>
<tr>
<td>Paved road</td>
<td>1.32</td>
<td>1.17</td>
</tr>
<tr>
<td>Static</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

**Table 2**—Measured vs. FEA predicted stresses.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Measured point</th>
<th>Stress (MPa)</th>
<th>FEA prediction (MPa)</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static and level loaded</td>
<td>Bin transition</td>
<td>14.26</td>
<td>15.99</td>
<td>10.80%</td>
</tr>
<tr>
<td></td>
<td>Upper bin corner</td>
<td>99</td>
<td>108.77</td>
<td>8.90%</td>
</tr>
<tr>
<td></td>
<td>Chassis Neck</td>
<td>15.21</td>
<td>15.46</td>
<td>1.60%</td>
</tr>
<tr>
<td>Unloading</td>
<td>Bin transition</td>
<td>34.4</td>
<td>38.01</td>
<td>9.50%</td>
</tr>
<tr>
<td></td>
<td>Upper bin corner</td>
<td>110.04</td>
<td>113.33</td>
<td>2.90%</td>
</tr>
<tr>
<td></td>
<td>Chassis Neck</td>
<td>40.95</td>
<td>42.34</td>
<td>3.20%</td>
</tr>
</tbody>
</table>
Using the same equipment for receiving the cane from loaders and harvesters and also to transport the cane to the yard for being unloaded by cranes leads to substantially heavier equipment with high impact on the fuel and maintenance costs. A significant number of mills, therefore, are returning to the practice of using smaller tipping wagons to receive the cane inside the field and deliver it to the specialised bigger road wagons for transport to the factory.

Different approaches and activities have been adopted to develop a new transport wagon design with a better cane load to wagon tare relation, without compromising the equipment reliability:

- Load exerted by cane on the side walls of a wagon bin has been modelled and experimentally confirmed (Cobo et al., 2008).
- Pull loads have been assessed using experimental stress analysis.
- FEA modelling of welded connections of thin walled structural members has been performed together with experimental evaluations (Castro et al., 2009).
- New unloading systems, less demanding of wagon strength, have been documented.
- A prototype of a 12 tonne side dumping wagon was developed and tested, with both mechanically harvested and hand cut cane (Figure 5).

Fuel consumption in cane transport

A theoretical model for a train of cane transport wagons was developed to predict pulling force and power and fuel consumption (Ascuntar, 2008). Figure 6 shows a simplified vehicle forces scheme. The model was confirmed with field experiments. The importance of weight reduction on the wagon structure was determined.

A complete cycle of cane supply operations was considered which consists of four main activities:

1. Empty wagons transported to the field.
2. Cane loading operations.
3. Loaded wagons transported to the factory.
4. Mill yard operations (weighing, sampling, unloading).

Typical fractions of time spent on each activity and average speeds of the main activities are shown in Table 3 for a train of six 12 tonne wagons pulled by a STX 275 tractor.
Table 3—Operational parameters during a cycle of cane supply for a train of six 12 tonne wagons pulled by a STX 275 tractor.

<table>
<thead>
<tr>
<th>Cycle activity</th>
<th>Average speed (km/h)</th>
<th>Fraction of time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>0.19</td>
</tr>
<tr>
<td>2</td>
<td>3.5</td>
<td>0.30</td>
</tr>
<tr>
<td>3</td>
<td>15</td>
<td>0.24</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>0.27</td>
</tr>
</tbody>
</table>

Field experiments were conducted on very fine Tepic Haplustert soils with 200 mm per year of precipitation and medium to high permeability. A CASE IH 9230 tractor (280 kW) was used together with a pull dynamometer developed by Cenicaña with a modified Holland hitch point (Figure 7, Gómez and Bejarano, 2007), a GPS and a fuel flow meter (Figure 8). Tractor position, speed, pull force and on-line fuel flow were recorded.

Fig. 6—Forces involved in a power consumption model for a towed system.

With:

- Wt: Tractor weight
- Frt: Tractive force
- V: Vehicle speed
- Rd: Reactive force of terrain, tractor’s front axis.
- W: Total weight (tare+cane)
- Rd: Reactive force of terrain, tractor’s rear axis
- α = Road slope
- Rd: Reactive force of terrain, wagon’s front axis
- FI: Inertia force
- Rd: Reactive force of terrain, wagon’s first rear axis
- Fair: Air resistance
- Rt: Reactive force of terrain, wagon’s second rear axis

Fig. 7—Holland hitch modified and fitted with strain gauges for pull force measurements.
Figure 9 compares available fuel energy (measured on-line) to energy dedicated to move the loaded vehicle, as calculated from pull force and train velocity. Results show that 76.8% of the fuel available energy is spent in the thermal and mechanical conversion including mechanical losses and motor vehicle displacement, indicating a very inefficient process.

Figure 10 presents fuel consumption for a tractor pulling five different train configurations over the same terrain, during a 500 s period and Table 4 shows the results of integrating the power vs. time curve to determine the total energy for each configuration. Figure 11 presents fuel consumption vs. towed weight for different towing speeds.
Fig. 10—Fuel consumption for five different load configurations.

**Table 4**—Ttractive energy and fuel consumption for different transported weights.

<table>
<thead>
<tr>
<th>Transported weight (tonne)</th>
<th>Ttractive energy (kJ)</th>
<th>Fuel consumption (l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>26.43</td>
<td>9016</td>
<td>0.96</td>
</tr>
<tr>
<td>35.57</td>
<td>9488</td>
<td>0.98</td>
</tr>
<tr>
<td>39.25</td>
<td>9632</td>
<td>1.06</td>
</tr>
<tr>
<td>58.81</td>
<td>12686</td>
<td>1.32</td>
</tr>
<tr>
<td>79.04</td>
<td>17628</td>
<td>1.55</td>
</tr>
</tbody>
</table>

Fig. 11—Fuel consumption vs towed weight for different towing speeds.

The model predicted a 5.3% fuel consumption reduction for a 10% decrease in wagon weight. For the same condition, experimental measurements so far show fuel consumption reductions of 5.6% at 10 km/h and 5.2% at 12 km/h (Figure 12).
More experiments are in progress to identify the influence of other variables such as tyre type, inflation pressure, and speed.

![Fig. 12—Weight reduction and fuel consumption.](image)

**Conclusions**

There was good agreement between FEA predicted stresses for wagon structures and experimental measurements. FEA modelling of welded connections of thin walled structural members can be used safely for design purposes.

Logistics analysis is an important tool for cost reduction. It has been possible to reduce up to 15% of resources in a mill with better coordination in cane loading, transport and unloading. Quality and opportunity of factory and harvesting personnel communication is a key logistic factor.

Also a good agreement was achieved between fuel consumption model predictions and experimental measurements. So far a 10% wagon tare reduction indicates around 5% saving of fuel in road transport for the complete cycle.

The developed dynamometer proved to be a useful tool for determining forces affecting wagon structures and energy consumption measurements. It can also be used to assess the impact of other variables such as tyre type and inflation pressure.

**Acknowledgements**

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**REFERENCES**


AMELIORATIONS POUR LE TRANSPORT ROUTIER DE LA CANNE A SUCRE

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MOTS-CLEFS: Transporte de la Canne, Consommation de Carburant, Modelage FEA.

Résumé

Le transport routier, la récolte manuelle ou mécanique et le déchargement de la canne à sucre sont les opérations les plus coûteuses pour l’industrie de la canne a sucre et de l’éthanol. Une étude complète du système de transport de canne, comprenant la logistique et la conception des caissons pour la canne, a été entreprise pour l’industrie sucrière colombienne. Des modèles pour prédire la consommation de carburant ont été développés et testés à l’aide de techniques comme le GPS et les mesures directes de débit de carburant pour les cycles opérationnels complets. L’influence du poids des caissons sur la consommation de carburant a été étudiée pour le cycle complet et on a utilisé le modèle FEA pour la conception et la construction des équipements. Les résultats montrent que des réductions de 5 % de frais de carburant sont obtenues avec une réduction de 10 % du poids structurel.

MEJORAS A UN SISTEMA DE TRANSPORTE DE CAÑA POR CARRETERA

Por

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PALABRAS CLAVE: Transporte de Caña, Consumo de Combustible, Elementos Finitos.

Resumen

De los costos del sistema global de producción de azúcar y etanol, los relacionados con las actividades de cosecha (manual y mecanizada), transporte por carretera y descarga de caña son los más significativos. Se desarrolla para la industria azucarera colombiana un estudio integral del aprovisionamiento de caña a las fábricas, que incluye desde la logística del sistema hasta el diseño de vagones. Se han desarrollado y probado modelos para predicción del consumo de combustible, usando técnicas como sistemas de posicionamiento global (GPS), medición de fuerza de tiro y de consumo directo de combustible para el ciclo completo de las operaciones. Se han efectuado análisis de sensibilidad para determinar la influencia del peso de los vagones en el consumo de combustible durante el ciclo completo y se ha usado modelamiento por Elementos finitos para el diseño y construcción de nuevo equipo. Los resultados muestran reducciones del 5% en el costo de combustible cuando se logra disminuir en un 10% el peso estructural de los vagones.
CANE TRASH AS FUEL

By

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KEYWORDS: Cane Trash, Energy, Trash Processing, Leaching.

Abstract
SUGARCANE dry trash, a residue in cane fields, has significant potential as a biomass fuel. It contains nearly 28% of the total energy content in the sugarcane crop. However, this potential fuel is wasted by burning it in open fields after sugarcane harvesting producing harmful emissions. In India, if all the cane trash be utilised to full potential, the national energy deficit can be reduced by 50%. Moreover, the sugar industry gets an additional 110% power export in the process. Unfortunately, the collection mechanisms in vogue are uneconomical and not suitable to realise the potential energy benefits. Deccan sugars, sugar mill of Nava Bharat Ventures Ltd has tried a collection mechanism by harvesting dry leaves along with cane and processing it through the milling tandem, thus increasing bagasse generation. Sugarcane trash has high alkali and silica content, which makes it unsuitable as boiler fuel directly. Trash processed with the cane supply is thoroughly washed in the milling process, thereby significantly reducing the alkali and silica content of the resultant bagasse. Harvesting and processing trash along with sugarcane seems to be a good method to make trash a suitable boiler fuel and realise its potential.

Introduction
The Indian Sugar Industry is progressing well in its efforts to expand the implementation of cogeneration. The industry is progressively achieving benchmarks in reduced process energy consumption. A few sugar mills have reduced steam consumption to 340 kg/tonne cane producing direct white consumption sugar by following the double sulfitation process. A few more are aiming to achieve steam consumptions of 300 kg/tonne cane.

In India, sugarcane cultivation is done manually except for the operations of land preparation and cane transportation for which tractors are used. Green cane harvesting is done manually. Green leaves and cane tops are used as fodder. Manual harvesting has become a serious production bottleneck threatening the survival of the sugar industry. Various types of mechanical harvesters are being tried in the recent past.

Sugarcane trash, the dry brown leaves attached to the cane stalk, to some extent forms mulch in the fields 5–6 months into the initial growth or ratooning period. Post harvest burning of trash is common practice, releasing harmful greenhouse gases like N₂O, CH₄ and CO₂ in addition to CO. Very few sugar mills having a cogeneration facility are trying to collect trash from the fields by using balers. Manual collection and transport of loose trash from fields is practised at certain mills.

Biomass has got a lot of potential in varied applications from power generation to plastics. There is a growing interest and need for an efficient biomass collection mechanism. Cane trash is a potential source of biomass with well established benefits as a fuel and manure. Appropriate collection mechanisms and attractive markets for trash will make sugarcane cultivation more profitable.

Deccan sugars have undertaken trials to demonstrate the efficient collection of trash by whole-of-crop harvesting and milling. This was to provide additional fuel to their 9 MW rated
boiler pressure: 43 bar (abs)] and 20 MW [rated boiler pressure: 87 bar (abs)] capacity cogeneration facilities. The associated factory process steam consumption has been reduced to 350 kg/tonne cane.

The mill is situated in coastal districts of Andhra Pradesh, South India in the tropics at 17°02′N latitude and 82°09′E longitude. Average altitude is 15 m above MSL. Cyclonic conditions prevail in the area during the cane growing period. Soil conditions and a cyclonic climate are the cause of severe sugarcane lodging. Land holdings are small averaging 1.1 ha. Many fields are not easily accessible for sugarcane transportation. Harvested sugarcane is shifted manually by laborers to a convenient place for loading.

The mill has the capacity to crush 450 000–585 000 tonnes of sugarcane annually. In the recent past, due to uneconomical margins for sugarcane farming with increased labour costs, the crop production reduced to 240 000 tonnes. As the crush rate reduced, we were able to trial this unique approach to trash collection.

Cane trash handling and utilisation–previous research and experiences

Sugarcane produces huge quantities of foliage; up to 40% of total biomass. On an average, 15–20 tonnes of cane trash are produced per hectare. However, the quantity varies with varieties and crop growth. Cane trash contains considerable amounts of plant nutrients. These nutrients can be conserved if recycled into the soil. However, the entire amount of trash obtained from cane fields cannot be utilised for mulching, as an excessively thick blanket of mulched trash can inhibit germination, harbors reptiles and results in poor cane growth.

Results obtained at the Regional Agriculture Research Station, Anakapalle, India led to the recommendation of 3 t/ha of trash mulching to conserve soil moisture and nutrients (Ramalingaswamy 1998). However, mulching is more effective in upland and light soil conditions. The 12 to 17 t/ha of surplus trash has to be economically utilised by proper collection.

Post-harvest trash burning causes loss of nutrients (Krishna, 2002). Cane stubbles get damaged due to the heat and cause delayed germination resulting in poor yield during ratooning. Burning trash generates intense heat ranging from 600°C to 800°C which kills beneficial soil microorganisms and earth worms. The global warming potential of gases such as N₂O and CH₄ in addition to CO₂ that are released during burning is of greater concern. N₂O is the most worrying emission because of its high global warming potential (300 times more damaging than CO₂).

Sugarcane has significant potential as a source of biomass fuel. Sucrose in the stalk only represents approximately 30% of the total energy of the above ground biomass of sugarcane. C₄ species like sugarcane will outperform C₃ species in their ability to accumulate biomass. The maximum above ground biomass growth can be as high as 550 kg/ha/day. When grown under rainfed conditions, sugarcane has one of the highest water use efficiencies of all crops in terms of water used per unit mass of biomass produced (Botha, 2009).

Energy potential in cane trash

Sugarcane is an energy crop produces the energy equivalent per hectare per cropping cycle of 95–114 barrels of crude oil (Botha, 2009; Ripoli, 2000; Rein, 2007; Krishna, 2002). 60% of the energy is transported to the mill as clean cane, 12% is utilised as fodder (young internodes and green leaves) and the rest 28% (trash) is predominantly burnt in the open (Ripoli, 2000; Rein, 2007; Krishna, 2002).

Cane trash is a potential fuel with a calorific value ranging from 3845–4375 kcal/kg on dry basis (Kurt woytuiik, 2006) having moisture in the range of 20–30%.

With an average yield of clean cane of 75–80 t/ha, each hectare of sugarcane cultivation has 12–17 tonnes of excess cane trash available. This is equivalent to a primary energy value of up to 50 000 kWh per hectare of sugarcane-cultivated land. However, associated activities in the process of generating energy from trash such as transportation, processing and energy extraction influence the actual electrical energy benefits reaped from cane trash.
Cane trash as fuel for power generation—the challenges

Field level challenges

Pricing mechanism—Farmer confidence
For a long time now, farmers have been accustomed to send fresh clean cane to the mill. Payment is made to farmers on a weight basis. Average recovery from the previous campaign is also considered in the payment system.

A suitable pricing mechanism for the whole-of-crop harvested cane has to be developed to provide sufficient confidence in farmers.

Collection and transport

Low bulk density
Low bulk density accounts for higher transportation and handling costs. Trash has a very low bulk density, which invariably increases the collection and transportation cost. Experiments at the mill have shown that the density of loose trash is in the range of 50–65 kg/m³. Cane stalk bundled with dry leaves is found to have a bulk density in the range of 220–230 kg/m³.

Baling is one alternative for reducing trash collection and transportation costs. Trash can be compacted to 242–306 kg/m³ using large rectangular balers (Hassuani et al., 2005). However, baling is energy intensive compared to trash collection along with cane.

Collection efficiency
It is observed that 56–84% of trash can be collected by raking and baling trash (Hassuani et al., 2005). We can achieve more than 95% trash recovery by harvesting trash along with cane.

Soil % in trash
The collection mechanism must also ensure that soil is not entrained with the trash during collection. Baling without a prior raking operation is found to have a soil content in the range of 5-6%. With the raking operation, the sand content in the bales is in the range of 1.5–2.0%. (Hassuani et al., 2005).

The soil cannot be easily separated and hence results in excessive erosion in boilers whereas, in the case of harvesting trash along with lodged cane, there is a possibility to provide a sand separation mechanism before processing it in the mill.

Factory level challenges

Fuel usage challenges

Total alkali, sulfates, chlorine and silica concentrations in trash
Alkali metals in conjunction with other inorganic components such as silica, sulfur and chlorine are primarily responsible for slagging and fouling, which reduce the boiler efficiency. These components are common in herbaceous crops. They play an important role in the plant metabolism (Kurt woytuik, 2006).

Volatile alkali metals at high temperatures form inorganic gases which react with other fuel components to exacerbate ash deposition problems by two primary mechanisms. The first mechanism is by reduction of the ash fusion temperature due to the formation of alkali silicates. The second mechanism is by condensation of alkali vapours on boiler tube surfaces, which react with sulfur to form alkali sulfates reducing the boiler effectiveness (Baxter and Jenkins, 1995). Chlorine assists in effective transport of alkali vapours to the boiler tube surfaces (Miles, 1995).

The tendency to form deposits or slag increases significantly at ash levels of between 0.17 kg/GJ to 0.34 kg/GJ. Fouling and possible slagging occurs above those total alkali concentration levels (Miles, 1995).

The total alkali concentration of the fuel can be reduced by blending with a processed fuel-like bagasse. However, composite data (calculated from analysis reports of raw cane trash and bagasse) presented in Figure 1 show that the total alkali, Cl and SO₃ concentration per unit energy is
still above the threshold level (0.17 kg/GJ) for fuel mixtures having trash contents greater than 20%. Boiler manufactures are recommending trash to bagasse ratio of 10:90 for the latest high pressure boilers.

![Graph showing alkali content in trash–bagasse fuel mixture per unit energy content at different mixture concentrations.](image)

Pilot scale experiments on a Cuba mill in Hawaii have shown that leaching by milling is very effective in reducing the total alkali, sulfur and chlorine content of trash. It is also observed that considerable improvement in leaching was achieved by decreasing the particle size (Kurt woytuik, 2006).

All herbaceous crops have higher concentrations of the alkali metals, chlorine, silica and sulfates. Leaching is already proven to improve fuel characteristics in the case of bagasse. Bagasse generated by milling trash along with cane is having the total alkali index well below the threshold 0.17 kg/GJ level because of the efficient leaching in milling.

**Trash processing challenges**

**Crushing rate**

The cane crushing rate is found to reduce by 2.3% for 1% increase in trash % cane processed in milling tandems, primarily due to increased fibre content. It is found that the fibre rate is not affected by processing additional trash along with cane (Kent, 2007).

**Energy consumption**

Electrical energy consumption at the milling station will theoretically increase due to the additional fibre content in trash. However, the lignin content, which generally provides the rigidity or hardness in fibre, is comparatively less in fibre of trash. Hence, the power consumption per tonne of fibre in trash will be less than that of fibre in cane stalk. There will also be an increase in steam consumption due to increased mixed juice % cane.

**Juice quality and sugar extraction**

It is observed that increase in trash processed along with cane during milling results in reduction in purity of juice, increased extraction of reducing sugars and loss of pol carried through extra fibre in trash. A 0.1 unit decrease in extraction and 0.3 units decrease in mixed juice purity was observed for 1% increase in trash % cane. (Kent, 2007)
In the current study, it is assumed that the effect of the above challenges for processing trash in a milling tandem can be managed within limits through minor changes to milling and sugar processing plants.

Methodology

Three trials of 440 minutes duration were undertaken by the mill to evaluate the potential and actual effects on the entire mill of using cane trash as fuel in the existing infrastructure. During the three trials, 89 tonnes of trash were processed along with 417 tonnes of clean cane. The cane received along with trash at the mill was fed to the cane carriers using grab unloaders and processed through three sets of knives, a cane shredder and a 4 milling tandem of 30 × 60’ size with underfeed rollers. The last mill is equipped with a grooved roller pressure feeding device.

The increased bagasse due to extra fibre content in trash is used as fuel for the cogeneration system. The cogeneration system constitutes a 64 t/h travelling grate boiler generating superheated steam at 43 bar (abs) and 415°C. In the campaign, 3000 tonnes of trash were processed intermittently but at regular intervals with cane in the mill.

Results and discussion

Harvesting and transport of trash along with cane

The work required for detrashing during harvesting has reduced but head load to be carried to the truck per hectare has increased. The cost of transportation has also increased due to reduced bulk density of trash along with cane in comparison with clean cane. During the trials, cane trash levels of around 21.4% of the total clean cane received at the sugar mill were recorded. The cane trash levels recorded during the trials are given in Figure 2.

Processing trash along with cane through mills

An effective analysis system is essential to arrive at an accurate price for sugarcane which is consistent with the existing cane payment framework. It is essential for the analysis system to provide sufficient confidence for farmers to participate in the harvesting of trash with cane. Unfortunately, core samplers and NIR analysers are not currently used as the basis for determining the sugarcane price. We had to adopt a random sampling and weight-based analysis system. We have demonstrated its working to the farmers for encouraging harvesting trash along with cane.

The fibre rate through the milling plant has decreased by 14.28% because of inadequate feeding facilities suitable for milling trash along with cane.

Imbibition

To maintain effective sucrose extraction, imbibition was increased to compensate for the increase in fibre content. Pol % bagasse remained at 1.8% for increase in imbibition % cane in the
range of 1.7–1.25 units for 1% increase in trash % cane. The pol in bagasse increased rapidly by further decreasing the increment in imbibition % cane (Table 1).

**Table 1**—Percentage increase in Imbibition % cane for 1% increase in trash % cane.

<table>
<thead>
<tr>
<th>Trial no.</th>
<th>Increase in imbibitions per unit increase in trash % cane</th>
<th>Pol % bagasse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial–1</td>
<td>1.781</td>
<td>1.8</td>
</tr>
<tr>
<td>Trial–2</td>
<td>1.280</td>
<td>1.8</td>
</tr>
<tr>
<td>Trial–3</td>
<td>0.762</td>
<td>2.01</td>
</tr>
</tbody>
</table>

**Extracted juice properties**

*Sucrose extraction in mixed juice*

**Table 2**—Mixed juice quantity (MJ) and % pol observed during trials.

<table>
<thead>
<tr>
<th>Trial no.</th>
<th>Normal values without trash</th>
<th>Values during the trials</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pol % MJ MJ % cane</td>
<td>Pol % MJ MJ % cane</td>
</tr>
<tr>
<td>Trial–1</td>
<td>10.53 108.65</td>
<td>7.21 149.86</td>
</tr>
<tr>
<td>Trial–2</td>
<td>8.1</td>
<td>133.78</td>
</tr>
<tr>
<td>Trial–3</td>
<td>7.42 146.20</td>
<td></td>
</tr>
</tbody>
</table>

**Table 3**—Decrease in sucrose extraction for 1% increase in trash % cane*.

<table>
<thead>
<tr>
<th>Trial no.</th>
<th>Decrease in sucrose extraction (kg / tonne cane)</th>
<th>Trash % clean cane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial–1</td>
<td>0.33</td>
<td>19.05</td>
</tr>
<tr>
<td>Trial–2</td>
<td>0.36</td>
<td>16.93</td>
</tr>
<tr>
<td>Trial–3</td>
<td>0.21</td>
<td>28.54</td>
</tr>
</tbody>
</table>

*derived from data in Table 2

Table 3 shows the effect on sucrose extraction of processing trash along with cane. As it is observed, there is a 0.21–0.36 kg per tonne cane decrease in sucrose extraction for 1% increase in trash % cane. Because of the relatively short nature of the trials, it was not possible to directly measure the effect of trash on sugar quality and recovery. However, the decrease in sucrose content mixed juice (Table 2) is a clear indicator of the effect on sugar recovery.

*Colour removal*

**Table 4**—Value of IU measurements made during trials.

<table>
<thead>
<tr>
<th>Trial no.</th>
<th>Mixed juice colour (normal value without trash)</th>
<th>Mixed juice colour during trials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial–1</td>
<td>19 146</td>
<td>46 000</td>
</tr>
<tr>
<td>Trial–2</td>
<td>32 669</td>
<td>32 669</td>
</tr>
<tr>
<td>Trial–3</td>
<td>35 403</td>
<td>35 403</td>
</tr>
</tbody>
</table>

**Table 5**—Colour removal during clarification process.

<table>
<thead>
<tr>
<th>Normal values without trash</th>
<th>Values during the trials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixed juice colour</td>
<td>Clear juice colour</td>
</tr>
<tr>
<td>19 146</td>
<td>17 783</td>
</tr>
</tbody>
</table>
From Table 4 above, there is considerable increase in mixed juice colour observed by processing trash along with cane during the trials. Starch content in the leaves is believed to be primarily responsible for the increased juice colour. There is an increase of between 550–1400 IU colour units in mixed juice for a 1% increase in trash % cane. However, as per Table 5, considerable removal of juice colour was observed in the juice clarification process. The residual colour in clear juice is easily removed in syrup clarification and crystallisation processes. Hence, trash was deemed to have no significant impact on the sugar colour of the product (Figure 3).

**Boiler performance**

Leaching of trash during milling ensured a clean fuel for the boiler. The analysis of the fuel showed concentration of alkali in ash well below the threshold level responsible for slagging. Figure 4 shows a comparison of measurements of concentrations of alkali Cl\(^-\) and SO\(_3^+\) ions in bagasse from clean cane, from trash processed along with cane, and with that of trash in its naturally occurring state.

The results have clearly shown that leaching effectively removes alkali content from trash. There was no noticeable change in the performance of the boiler vis-à-vis flue gas temperature profile as shown in Figure 5.
Increased sand content in bed ash is observed, indicating excess silica being entrained with the trash during trials. Installation of sand separators at the mill feeding point would reduce the excess sand content in cane with trash.

There was an increase in the oxygen content in flue gas during the trials (Figure 6) which may presumably be due to increased moisture content to 52% or the changed fuel properties.

Cost of trash

To understand the economics of collection and harvesting trash as a fuel, a value for trash has been derived by assigning costs to various activities and effects involved (Table 6).

Table 6—Incremental cost of trash as fuel by processing it along with cane in the milling tandem.

<table>
<thead>
<tr>
<th>S. no</th>
<th>Description</th>
<th>Value (US$/tonne of trash)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Trash price paid to farmer</td>
<td>4.0</td>
</tr>
<tr>
<td>2</td>
<td>Transport charges</td>
<td>5.0</td>
</tr>
<tr>
<td>3</td>
<td>Power consumption for leaching trash (90 kWh / tonne fibre and $80 / MWh)</td>
<td>5.0</td>
</tr>
<tr>
<td>4</td>
<td>Steam consumption due to increased imbibition (0.02 t bagasse @ $30 per tonne bagasse)</td>
<td>0.6</td>
</tr>
<tr>
<td>5</td>
<td>Sugar loss through bagasse (Assumed sugar price of $460/tonne)</td>
<td>13.0</td>
</tr>
<tr>
<td>6</td>
<td>Sugar loss through molasses (Assumed sugar price of $460/tonne)</td>
<td>7.0</td>
</tr>
<tr>
<td>7</td>
<td>Realization from 1% on cane increased molasses @ $120/t molasses (due to increment in juice RS content)</td>
<td>– 6.0</td>
</tr>
<tr>
<td>8</td>
<td>Cost of trash</td>
<td>28.6</td>
</tr>
</tbody>
</table>
Hence, a valuable fuel is available to the mill at $28.6 / tonne or $1.66 / GJ. Hence, processed trash is far more attractive than crude oil [$8.7 / GJ] or coal with carbon capture [$4.8/GJ] (Botha, 2009).

Conclusion

In a country like India, a farmer is used to delivering clean cane to the mill and receiving payment on the basis of weight and previous campaign mill average recovery. The impact for an Indian scenario of collecting and milling trash along with cane has been undertaken. Apprehensions associated with factors such as deterioration in sugar quality, clinker formation and fouling in boiler and resistance from farming community for such change in harvesting and transportation can be overcome to some extent by these successful trials.

These preliminary trials have yielded interesting results such as:

1. The dried leaves, non-cane portion for milling worked out to be approximately 20% of clean cane on weight basis.
2. Raw cane trash (i.e. prior to milling) has a higher calorific value in the range of 3845–4375 kcal/kg on dry basis.
3. Leaching trash in mills effectively reduced fuel alkali concentration delivering a processed fuel to the boiler with minimal risk of slagging.
4. Though transport of cane along with trash from cane fields to sugar mill involved greater transportation costs, trash contributed considerably to the increase in quantity of fuel increasing the net power export from the cogeneration plant.
5. There is a significant reduction in crushing capacity which can be moderately increased by uniform feeding.
6. The colour content of the mixed juice increased due to compounds extracted from the trash by the milling process. However, the increased colour content of mixed juice did not ultimately affect the quality of product sugar as the colour was removed in the juice clarification, syrup clarification and crystallisation processes.

Through the experience gained in this study, it has been established that the following criteria for selecting fields suitable for harvesting trash along with cane make the activity more attractive

- Trash collection should be from fields within 15 km distance from mill
- Erect (non lodging) cane varieties should be selected
- High biomass yielding cane varieties should be selected

Effective separation of sand, uniform feeding of raw material to milling tandem, evolution of right payment mechanism for dry trash based on either core sampler or NIR technique are essential in future to continue this activity.

Summarising, crushing of cane along with trash appears to be of extreme use for increased cogeneration of power. Crushing of cane along with trash reduces atmospheric pollution and helps in reducing global warming. However, the reduction in crushing capacity can adversely affect the mill operations when there is sufficient cane available to be crushed. Suitable additional milling capacity to process trash along with cane is inevitable.

These remarkable advantages of crushing cane along with trash warrant further detailed studies to help alleviate power shortages in India and reduce global warming.

Acknowledgements

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PAILLE DE CANNE COMME CARBURANT

Par

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MOTS CLEFS: Paille de Canne, Énergie, Traitement de la Paille, Lixiviation.

Résumé

LA PAILLE de canne, un résidu dans les champs de canne à sucre, a un potentiel important comme un carburant de la biomasse. Elle contient près de 28% de la teneur totale d'énergie dans la culture de la canne. Toutefois, ce combustible potentiel est gaspillé par le feu en plein champ après la récolte, produisant des émissions nocives. En Inde, si toute la paille de canne est utilisée, le déficit énergétique national peut être réduit de 50%; en outre, l'industrie sucrière obtient une exportation d’énergie de 110%. Malheureusement, les mécanismes pour récolter la paille ne sont pas

économiques et on n’obtient pas les avantages possibles. La sucrière de Navoï Bharat Ventures Ltd (Deccan) a essayé de récolter la paille avec la canne et de traiter le tout aux moulin, augmentant ainsi la génération de bagasse. La paille contient beaucoup d’alcalins et de silice, ce qui ne convient pas aux chaudières. La paille a été soigneusement lavée aux moulin, réduisant ainsi les alcalins et la silice dans la bagasse. La récolte et le traitement de la paille avec la canne semblent être une bonne méthode pour transformer la paille en un combustible de chaudière approprié, ce qui réalise son potentiel.

RESIDUO AGRICOLA DE LA CAÑA COMO COMBUSTIBLE

Por

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PALABRAS CLAVE: Residuos, Energía, Procesamiento de Residuos.

Resumen

El residuo de cosecha de caña seco dejado en el campo tiene un potencial significativo como biomasa combustible. Contiene cerca del 28% del total de la energía de la caña. Sin embargo este potencial es desperdiciado por las quemas abiertas en campo después de la cosecha produciendo emisiones nocivas. En India, si todos los residuos se utilizan en todo su potencial, el déficit nacional de energía puede reducirse en un 50%. Adicionalmente la industria azucarera obtiene una exportación adicional de energía eléctrica del 110%. Desafortunadamente los mecanismos de recolección disponibles no son económicos y no permiten el logro de los beneficios potenciales. Deccan Sugars, ingenio de Nava Bharat Ventures Ltd ha ensayado diferentes alternativas para la recolección de hojas secas para molerlas en el tándem, incrementando la producción de bagazo. Los residuos tienen altos contenidos de álcalis y silice lo que los hace no aptos para uso directo en las calderas. Al procesarlos con la caña son totalmente lavados en el proceso de molienda reduciendo los contenidos de álcalis y silice del bagazo resultante. Cosechar y procesar los residuos con la caña parece ser un buen método para convertir los residuos en un combustible adecuado para las calderas y aprovechar su potencial.
COGENERATION – A NEW SOURCE OF INCOME FOR SUGAR AND ETHANOL MILLS
or BIOELECTRICITY—A NEW BUSINESS

By

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KEYWORDS: Cogeneration, Bioelectricity,

Abstract
COGENERATION, energy efficiency and surplus power production are old topics in Brazilian sugarcane mills. However, until 2003, they lacked institutional and regulatory support, when the Brazilian government decided to encourage and regulate alternative electricity production. Today, bioelectricity production in sugarcane mills and sale of the surplus power to the grid is a consistently fast-growing new business. Installed bioelectricity capacity in the Brazilian sugar industry reached 1800 MW in 2007/08. In a public auction on August 8th, 2008, the Brazilian Energy Agency (Agência Nacional de Energia Elétrica – Aneel) determined the bidding rules, including the maximum price to be paid for bioelectricity as reserve energy for the next 15 years, resulting in a total installed capacity of the auction winners of 2385 MW. Projections for 2020/21 foresee that the supply to the grid will be equivalent to 14 400 MW average, and that the revenue generated with this new business will be similar to Brazilian sugar production. This scenario opens opportunities for new energy optimisation technologies. This paper is focused on the use of sugarcane from an energy point of view, and how to (a) maximise the use of energy contained in sugarcane; (b) minimise energy consumption by the sugar and ethanol mills; (c) integrate the electricity production process into the sugar and ethanol process; (d) maximise surplus electricity production. New technologies are integrated to the mill to improve the energy balance: electrical/mechanical drives via planetary gearbox and frequency inverters or electro-hydraulic drives to milling units; fermentation at higher ethanol content using absorption chillers to permit lower temperatures; combined pressurised and vacuum distillation; membrane utilisation for dewatering and dehydration; biogas-from-vinasse production and its subsequent use as fuel; use of sugarcane straw (sugarcane crop residues, i.e. tops, leaves and straw) for fuel; multifuel boilers with high pressure, high temperature and high efficiency (120 bar(g), 530ºC, 89% – LHV); condensation/extraction turbogenerator. Three hierarchical stages of technology are presented: sugarcane mills of first generation, second generation and third generation. The ‘Bioelectricity State-of-the-Art Mill’ is presented, and innovations are considered in the design of the complete sugarcane mill.

Introduction
Sugar and ethanol plants in Brazil have operated cogeneration systems for a long time. Until 2003, almost all cycles used by the mills operated with back-pressure turbo-alternators. Although the Brazilian industries have technology for high-pressure cogeneration systems, they have not been
used by the mills (Olivério and Ordine, 1987; Olivério et al., 1989). Demand specifically for power from biomass and, particularly, the lack of a well developed market for sale of the surplus energy did not attract investment in more efficient generation systems. The lack of transmission lines connected to the mills has also contributed negatively to the implementation of cogeneration systems to produce surplus energy for export to the grid. Investment in transmission lines was discouraged by the absence of regulations in the sector.

Therefore, the mills energy balances did not consider surplus power generation. Only low-efficiency cogeneration projects were contracted, consisting of low-pressure and low-heat efficiency boilers and turbogenerators, with use of low-efficiency steam drives. Processes were designed for high steam consumption because there was more than enough power produced in the mills and, as a result, optimisation was not needed.

With the increase in electricity demand in recent years, and the imminent risk of blackouts as a result of insufficient capacity, the Brazilian government decided to support and regulate power generation and distribution.

The government quickly diversified the national electric power program to explore the potentials of every power generation sector. In 2002, Proinfa was launched, with the objective of guaranteeing the price of the energy produced from alternative sources and to stimulate investment in cogeneration and electricity export to the grid (Olivério and Ribeiro, 2006). Besides Proinfa, the government also organised four auctions to sell the surplus power produced from biomass.

Along with the new rules, new concepts of cogeneration were designed for the mills, and more modern and efficient technologies began to be used in the cogeneration systems and production processes. Such technologies were grouped into the following categories:

- **First Generation:** the optimised technologies commercially available to the sugar and ethanol mills; the state-of-the-art solution.
- **Second Generation:** this includes the anaerobic digestion of the vinasse for biogas production to be used as a fuel in high-pressure boilers. It also includes the use of sugarcane residues (referred to as straw, which are tops, green and dry leaves) in the boilers.
- **Third Generation:** this is the development of economically feasible technologies for bagasse and straw gasification to be used in combined cycles for surplus power production in the mills.

**Energy valuation of sugarcane—surplus bioelectricity production process in sugar and ethanol mills**

The energy contained in sugarcane was largely underexploited prior to 2003. The Brazilian mills focused only on the extraction of energy contained in the sugarcane juice, ignoring, in other words, wasting the energy contained in the bagasse and straw (sugarcane crop residues, that means: tops, leaves and straw). By making use of the juice exclusively we can say that only 1/3 of the energy contained in sugarcane is used efficiently.

The remaining energy in sugarcane (2/3) is present in bagasse and straw, an energy that was underutilised because the energy efficiency of the mills’ cogeneration systems was very low. Regarding the energy contained in straw, this is completely lost because it is burnt in the field before harvesting. The loss of the energy present in straw is very high, representing 1/3 of the total energy contained in sugarcane (Olivério, 2003).

If we sum up the three components of energy contained in one tonne of sugarcane, we will see that such energy corresponds to approximately 1.2 barrels of crude oil, as shown in Table 1. Table 1 also shows the possible transformations of each component of energy as well as its equivalence in barrels of crude oil. By summing up the energy available in total sugarcane to be produced in the Brazilian 2010 season, we will have $1.17 \times 10^{15}$ kcal available. Current and 2010 projected figures are almost the same.
Table 1—Sugarcane energy potential (Olivério, 2003; Olivério and Ribeiro, 2006).

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<thead>
<tr>
<th></th>
<th>Sugar – the cheapest food in the world (in kcal)</th>
<th>Bioethanol – clean, renewable fuel</th>
<th>Energy contained in 1 barrel of crude oil 1386 x 10³ kcal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/3 from juice</td>
<td>Sugars – 153 kg 608 x 10³ kcal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/3 from bagasse</td>
<td>Bagasse w/ 50 moisture – 276 kg 598 x 10³ kcal</td>
<td>Electricity – clean, renewable fuel</td>
<td></td>
</tr>
<tr>
<td>1/3 from straw</td>
<td>Straw w/ 15% moisture – 165 kg 512 x 10³ kcal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1718 x 10³ kcal</td>
<td></td>
<td>1 tonne of cane = 1.2 barrels crude oil</td>
</tr>
</tbody>
</table>

Compared to UK, which consumes energy from crude oil, the total energy available in sugarcane produced in Brazil is 124% of the energy from oil (9.41 x 10¹⁴ kcal) consumed in UK. The energy available in Brazil from sugarcane is 80% of the energy from oil consumed in Germany and 42% of the energy consumed in Japan.

The amount of energy present in sugarcane is huge and is being wasted; for this reason, a production increase of surplus power in the mills to make better use of this energy should be pursued. By means of the equation below, we can see how to increase surplus power generation:

Maximum surplus power in the mill (\(=\)) Maximum use of the energy available in sugarcane (\(\rightarrow\)) Minimum consumption in the mill processes

The maximum surplus energy equation (Olivério, 2008; 2009) is very simple, but it helps to understand all necessary changes in the mill for maximum surplus generation.

First, let’s analyse the part of the equation that aims at the maximum use of the energy available. Here we should include the use of surplus cane bagasse as a fuel. By using bagasse, the mill will produce more steam than the process requires. It can also replace the back-pressure turbines by condensing turbines with controlled extraction. Another item to be added in the equation is the use of high-pressure, high-temperature boilers with high energy efficiency. Similar to the above, more steam will be produced for condensation besides a higher enthalpy drop in the turbine.

Let us analyse now the part of the equation for minimum energy consumption in the plant. It is necessary to reduce steam consumption in the sugar and ethanol processes to have more surplus steam for condensation and, as a consequence, higher surplus generation. It is also possible to replace the inefficient steam drives by more efficient electrical, electromechanical or electro-hydraulic drives. Therefore, there will be more energy produced with a positive balance in the replacement of the steam drives.

Technologies to maximise surplus bioelectricity production

According to the technological hierarchy presented earlier, let’s now detail the technologies used to maximise the surplus power generation by means of a case study. We will present the technological innovations of first and second generation, which are available in commercial scale. The third generation technologies will be presented in the next section, as part of the prospects for bioelectricity production. For our case study, a typical sugar and ethanol mill configuration will be used as a base case with specifications shown in Table 2. We emphasise that, as far as energy is concerned, the specifications of the chosen base case are typically prevalent in Brazil, with more than 70% of the mills with this energy profile.
Table 2—Typical configuration of a sugar and ethanol mill (*).  

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crushing capacity – tonnes of cane/hour</td>
<td>500 TCH</td>
</tr>
<tr>
<td>Crushing capacity – tonnes of cane/day</td>
<td>12 000 TCD</td>
</tr>
<tr>
<td>Effective operation days in one year</td>
<td>180 d/y</td>
</tr>
<tr>
<td>Crushing capacity – tonnes of cane/season</td>
<td>2 160 000 TCS</td>
</tr>
<tr>
<td>Boiler: steam pressure/temperature</td>
<td>21 bar(g)/ 320°C</td>
</tr>
<tr>
<td>Fibre % cane</td>
<td>13%</td>
</tr>
<tr>
<td>Process steam consumption (1.5 bar(g))</td>
<td>500 kg steam/ tc</td>
</tr>
<tr>
<td>Lower Heating Value (LHV) of bagasse (50% wet)</td>
<td>1800 kcal/Kg</td>
</tr>
<tr>
<td>Straw: use of 50% of straw collected with the cane</td>
<td>2058 kcal/kg</td>
</tr>
<tr>
<td>(straw weight :17% weight of clean cane, 40% moisture) – LHV:..</td>
<td></td>
</tr>
<tr>
<td>1 000 000 L of anhydrous bioethanol/day –</td>
<td>180 000 000 L bioethanol/season</td>
</tr>
</tbody>
</table>

(*) Ref.: ASSIS, P.E.P., INEE, 07/11/01, RIBERÃO PRETO

First generation technologies

Table 2 contains data for preparation of the energy balance of the sugar and ethanol mills. Figure 1 is a flowchart of a typical mill that does not produce surplus power and represents the energy balance of the base case represented in Table 2. Observing and understanding the flowchart are important to understand the technological innovations that will be described.

In the flowchart can be seen the hourly crushing capacity (500 tonnes of cane) and the respective bagasse generation. In the sequence we can see the strategic reserve, 5% (6.5 t/h) of the total bagasse produced, for the plant start-up, re-starts and heating, once at this moment sugarcane is not being processed and generating bagasse to be used in the boiler. We can also see the surplus bagasse, which represents 8.11% (11.4 t/h) of the total.

If we analyse the other end of the flowchart we can find the process steam requirements for production (492 tonnes of steam/tonne of processed cane). By linking the bagasse to the process, we have the boilers, turbogenerators and pressure-reducing valves which will be the goal of the technological innovations, besides the reduction of steam consumption in the production process so that we can draw the maximum energy contained in sugarcane.
In this mill configuration we can see the use of pressure-reducing valves to satisfy the varying process steam demands.

Starting from the configuration of Figure 1 (Olivério, 2008; 2009) and using the equation of maximum energy generation, as presented earlier, a step-by-step overview of the technological innovations and their corresponding surplus power generation is given, until we reach the configuration called ‘State-of-the-Art Mill’.

To facilitate the understanding of the technological innovations that will be presented step by step, Table 3 summarises the operational conditions of the elected plant for our case study.

This same table will be presented at the end of each innovation, showing the changes in process and facilitating the understanding of the changes.

### Table 3—Summary of the operational conditions of the case study plant.

<table>
<thead>
<tr>
<th></th>
<th>Current</th>
<th>After changes</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugarcane crushed/year</td>
<td>2 160 000</td>
<td>–</td>
<td>TCS</td>
</tr>
<tr>
<td>Sugarcane crushed/hour</td>
<td>500</td>
<td>–</td>
<td>TCH</td>
</tr>
<tr>
<td>Amount of bagasse produced</td>
<td>136.8</td>
<td>–</td>
<td>t/h</td>
</tr>
<tr>
<td>Bagasse burnt</td>
<td>118.9</td>
<td>–</td>
<td>t/h</td>
</tr>
<tr>
<td>Steam produced</td>
<td>254.1</td>
<td>–</td>
<td>t/h</td>
</tr>
<tr>
<td>Steam consumed in the process</td>
<td>492</td>
<td>–</td>
<td>kgs/tc</td>
</tr>
<tr>
<td>Steam pressure</td>
<td>21</td>
<td>–</td>
<td>bar(g)</td>
</tr>
<tr>
<td>Steam temperature</td>
<td>320</td>
<td>–</td>
<td>ºC</td>
</tr>
<tr>
<td>Steam flow at 1.5 bar(g)</td>
<td>187.2</td>
<td>–</td>
<td>t/h</td>
</tr>
<tr>
<td>Steam flow at the pressure-reducing valve</td>
<td>59.9</td>
<td>–</td>
<td>t/h</td>
</tr>
<tr>
<td>Steam flow for condensation turbogenerator</td>
<td>0</td>
<td>–</td>
<td>t/h</td>
</tr>
<tr>
<td>Total power produced</td>
<td>6.5</td>
<td>–</td>
<td>MW</td>
</tr>
<tr>
<td>Power consumed by the plant</td>
<td>6.5</td>
<td>–</td>
<td>MW</td>
</tr>
<tr>
<td>Surplus power</td>
<td>0</td>
<td>–</td>
<td>MW</td>
</tr>
</tbody>
</table>

**Generation of 4.9 MW of surplus power**

A simple strategy to produce 4.9 MW of surplus power is proposed. This strategy consists of replacing the pressure-reducing valve by a back-pressure turbogenerator. When the turbogenerator is used to reduce the pressure of the 59.9 t/h of make-up steam, 4.9 MW of electricity is produced for export to the grid (see Table 4).

**Production of 8.7 MW of surplus power**

A total of 8.7 MW of surplus power can be generated with the utilisation of higher levels of surplus bagasse. In addition to the 5% reserve for plant re-starts, there is a bagasse surplus of 8.1% (11.4 t/h).

The strategy proposed here is to increase the boiler capacity by making changes in the furnace, so that the surplus bagasse can be burnt. By burning the surplus bagasse, steam output will be 278.6 t/h.

The additional 20.7 t/h of steam to be produced in the boilers will be used to replace the pressure-reducing valve by a condensing/extracting turbogenerator. The flow of steam (surplus to process heating requirements) passing to the condensing turbine increases production to 8.7 MW of surplus power (see Table 5).
Table 4—Configuration after the changes prescribed for generation of 4.9 MW of surplus power.

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After changes</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugarcane crushed/year</td>
<td>2,160,000</td>
<td>2,160,000</td>
<td>TCS</td>
</tr>
<tr>
<td>Sugarcane crushed/hour</td>
<td>500</td>
<td>500</td>
<td>TCH</td>
</tr>
<tr>
<td>Bagasse produced</td>
<td>136.8</td>
<td>136.8</td>
<td>t/h</td>
</tr>
<tr>
<td>Bagasse burnt</td>
<td>118.9</td>
<td>118.9</td>
<td>t/h</td>
</tr>
<tr>
<td>Steam produced</td>
<td>254.1</td>
<td>254.1</td>
<td>t/h</td>
</tr>
<tr>
<td>Steam consumption in the process</td>
<td>492</td>
<td>492</td>
<td>kgs/tc</td>
</tr>
<tr>
<td>Steam pressure</td>
<td>21</td>
<td>21</td>
<td>bar(g)</td>
</tr>
<tr>
<td>Steam temperature</td>
<td>320</td>
<td>320</td>
<td>ºC</td>
</tr>
<tr>
<td>Steam flow at 1.5 bar(g)</td>
<td>187.2</td>
<td>247.1</td>
<td>t/h</td>
</tr>
<tr>
<td>Steam flow at the pressure-reducing valve</td>
<td>59.9</td>
<td>0</td>
<td>t/h</td>
</tr>
<tr>
<td>Steam flow for condensation turbogenerator</td>
<td>0</td>
<td>–</td>
<td>t/h</td>
</tr>
<tr>
<td>Total power produced</td>
<td>6.5</td>
<td>11.4</td>
<td>MW</td>
</tr>
<tr>
<td>Power consumed by the plant</td>
<td>6.5</td>
<td>6.5</td>
<td>MW</td>
</tr>
<tr>
<td>Surplus power</td>
<td>0</td>
<td>4.9</td>
<td>MW</td>
</tr>
</tbody>
</table>

Table 5—Configuration after the changes prescribed for production of 8.7 MW.

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After changes</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugarcane crushed/year</td>
<td>2,160,000</td>
<td>2,160,000</td>
<td>TCS</td>
</tr>
<tr>
<td>Sugarcane crushed/hour</td>
<td>500</td>
<td>500</td>
<td>TCH</td>
</tr>
<tr>
<td>Bagasse produced</td>
<td>136.8</td>
<td>136.8</td>
<td>t/h</td>
</tr>
<tr>
<td>Bagasse burnt</td>
<td>118.9</td>
<td>130.3</td>
<td>t/h</td>
</tr>
<tr>
<td>Steam produced</td>
<td>254.1</td>
<td>278.6</td>
<td>t/h</td>
</tr>
<tr>
<td>Steam consumption in the process</td>
<td>492</td>
<td>492</td>
<td>kgs/tc</td>
</tr>
<tr>
<td>Steam pressure</td>
<td>21</td>
<td>21</td>
<td>bar(g)</td>
</tr>
<tr>
<td>Steam temperature</td>
<td>320</td>
<td>320</td>
<td>ºC</td>
</tr>
<tr>
<td>Steam flow at 1.5 bar(g)</td>
<td>247.1</td>
<td>250.9</td>
<td>t/h</td>
</tr>
<tr>
<td>Steam flow at the pressure-reducing valve</td>
<td>0</td>
<td>0</td>
<td>t/h</td>
</tr>
<tr>
<td>Steam flow for condensation turbogenerator</td>
<td>–</td>
<td>20.7</td>
<td>t/h</td>
</tr>
<tr>
<td>Total power produced</td>
<td>11.4</td>
<td>15.2</td>
<td>MW</td>
</tr>
<tr>
<td>Power consumed by the plant</td>
<td>6.5</td>
<td>6.5</td>
<td>MW</td>
</tr>
<tr>
<td>Surplus power</td>
<td>4.9</td>
<td>8.7</td>
<td>MW</td>
</tr>
</tbody>
</table>

Production of 34.8 MW of surplus power

In the previous steps, there was no need for major technical innovation to meet 8.7 MW of surplus power. The focus of the next strategy will be the boilers, which will be replaced by equipment with high thermal efficiency, high pressure and high temperature (65 bar(g) / 485ºC). The efficiency of the condensing/extracting turbogenerator is also assumed to be increased. In this scenario, the equipment is assumed to be upgraded to include features such as:

- De-super heating system for better outlet steam temperature control.
- Fully automated systems for ash removal.
- Single-pass evaporators eliminating maintenance of the stream-gases baffles.
- Cooled grates allowing high temperature of the combustion air.
- Heat exchangers designed for greater heat recovery.
- Turbines with high isentropic efficiency.
By adding these features, steam production will be 293.8 t/h, which will be directed to a condensing extracting turbo-generator. Extraction at 21 bar(g) for the process equipment drives is assumed; the equipment drives operate at 1.5 bar(g) of back-pressure, because extraction of the same goes to the process. The other extraction is 1.5 bar(g) to meet the remainder of the process steam demand. The remaining 38.6 t/h of steam will pass through the condensing turbine stage. With this configuration, 34.8 MW of steam will be produced (see Table 6).

### Table 6—Configuration after the changes prescribed for production of 34.8 MW.

<table>
<thead>
<tr>
<th></th>
<th>Previous</th>
<th>After changes</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugarcane crushed/year</td>
<td>2 160 000</td>
<td>2 160 000</td>
<td>TCS</td>
</tr>
<tr>
<td>Sugarcane crushed/hour</td>
<td>500</td>
<td>500</td>
<td>TCH</td>
</tr>
<tr>
<td>Bagasse produced</td>
<td>136.8</td>
<td>136.8</td>
<td>t/h</td>
</tr>
<tr>
<td>Bagasse burnt</td>
<td>130.3</td>
<td>130.3</td>
<td>t/h</td>
</tr>
<tr>
<td>Steam produced</td>
<td>278.6</td>
<td>293.8</td>
<td>t/h</td>
</tr>
<tr>
<td>Steam consumed in the process</td>
<td>492</td>
<td>492</td>
<td>kgs/tc</td>
</tr>
<tr>
<td>Steam pressure</td>
<td>21</td>
<td>65</td>
<td>bar(g)</td>
</tr>
<tr>
<td>Steam temperature</td>
<td>320</td>
<td>485</td>
<td>ºC</td>
</tr>
<tr>
<td>Steam output at 1.5 bar(g)</td>
<td>250.9</td>
<td>248.2</td>
<td>t/h</td>
</tr>
<tr>
<td>Steam output at the pressure-reducing valve</td>
<td>0</td>
<td>0</td>
<td>t/h</td>
</tr>
<tr>
<td>Steam output for the condensation turbogenerator</td>
<td>20.7</td>
<td>38.6</td>
<td>t/h</td>
</tr>
<tr>
<td>Total power produced</td>
<td>15.2</td>
<td>41.3</td>
<td>MW</td>
</tr>
<tr>
<td>Power consumed by the plant</td>
<td>6.5</td>
<td>6.5</td>
<td>MW</td>
</tr>
<tr>
<td>Surplus power</td>
<td>8.7</td>
<td>34.8</td>
<td>MW</td>
</tr>
</tbody>
</table>

### Production of 40.7 MW of surplus power

The focus in this scenario is on the minimum consumption of power by the plant: reduction of the process steam consumption and replacement of steam drives by electromechanical or electro-hydraulic drives. Reduction of process steam consumption from 492 kg steam/tonne of cane to 400 kg/tc is possible with the technological innovations described below.

It is possible to bring down the process steam consumption to 400 kg/tc approximately, by designing the fermentation unit to receive more concentrated juice and then produce wine with higher alcohol content (11.0ºGL or higher), which permits that the distillation unit operates with a specific steam consumption of 2.6 kg/litre of anhydrous ethanol. This requires that the fermentation unit be automated and a CIP (cleaning-in-place) system implemented to keep the process heat transfer surfaces in good condition. Production of anhydrous ethanol utilises molecular sieve technology with low steam consumption. In addition, it is important to use indirect vapours from first effect for the distillery heating by using falling-film evaporators, which operate with very low load loss. The results of this scenario are summarised in Table 7.

### Production of 50.7 MW of surplus power. The State-of-the-Art Mill

To obtain 50.7 MW of surplus power and introduce the state-of-the-art mill, again we refer to the maximum surplus energy equation. By observing the part of the equation relating to maximum use of the available energy, we will replace the 65 bar(g)/485ºC boilers by 100 bar(g)/530ºC boilers, which have the following technological advances:

- Single drum boilers.
- A suspension fired combustion system. This system ensures stable combustion operation and rapid response to changes in steam demand during operation. With systems of this type, an increase of the steam generation capacity can be expected,
with the greater vertical dimension of the boiler permitting adequate dimensioning of the furnaces.

- Reaction turbogenerators. These are more efficient equipment.
- Automation. Appropriate automation systems for boilers, turbogenerators and total process consumption of 2.0 kg steam/litre of anhydrous ethanol.

**Table 7**—Configuration after the changes prescribed for production of 40.7 MW.

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After changes</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugarcane crushed/year</td>
<td>2 160 000</td>
<td>2 160 000</td>
<td>TCS</td>
</tr>
<tr>
<td>Sugarcane crushed/hour</td>
<td>500</td>
<td>500</td>
<td>TCH</td>
</tr>
<tr>
<td>Bagasse produced</td>
<td>136.8</td>
<td>136.8</td>
<td>t/h</td>
</tr>
<tr>
<td>Bagasse burnt</td>
<td>130.3</td>
<td>130.3</td>
<td>t/h</td>
</tr>
<tr>
<td>Steam produced</td>
<td>293.8</td>
<td>293.8</td>
<td>t/h</td>
</tr>
<tr>
<td>Process steam consumption</td>
<td>492</td>
<td>400</td>
<td>kgs/tc</td>
</tr>
<tr>
<td>Steam pressure</td>
<td>65</td>
<td>65</td>
<td>bar(g)</td>
</tr>
<tr>
<td>Steam temperature</td>
<td>485</td>
<td>485</td>
<td>ºC</td>
</tr>
<tr>
<td>Steam flow at 1.5 bar (g)</td>
<td>248.2</td>
<td>210.3</td>
<td>t/h</td>
</tr>
<tr>
<td>Steam flow at the pressure-reducing valve</td>
<td>0</td>
<td>0</td>
<td>t/h</td>
</tr>
<tr>
<td>Steam flow for condensation turbogenerator</td>
<td>38.6</td>
<td>76.5</td>
<td>t/h</td>
</tr>
<tr>
<td>Total power generated</td>
<td>41.3</td>
<td>58.7</td>
<td>MW</td>
</tr>
<tr>
<td>Power consumed by the plant</td>
<td>6.5</td>
<td>18</td>
<td>MW</td>
</tr>
<tr>
<td>Surplus power</td>
<td>34.8</td>
<td>40.7</td>
<td>MW</td>
</tr>
</tbody>
</table>

To reduce process steam consumption to nearly 300 kg steam/tc, it is necessary to:

- Maximise the heat recovery of the condensate and make use of the flush vapours heat.
- Increase the alcohol content in fermentation to the range of 13.0ºC with the use of a fermentation chiller-type cooling system to permit operation in lower temperatures (e.g. 28.0ºC), steam consumption in distillation will be lower. To reduce the use of Power, a lithium – bromide (LiBr) absorption chiller should be used (using the hot stillage as a heating source), instead of traditional chillers (mechanical compression type: reciprocating, centrifugal, screw) that need more energy.
- Use split-feed distillation which can reduce specific steam consumption to levels below 1.8 kg of steam/litre of ethanol.
- Use membranes for ethanol dehydration, which also contributes to reduce steam consumption as compared with molecular sieves. Total steam required will be 2.0 kg/litre of anhydrous ethanol. This scenario is summarised in Table 8.

**Table 8**—Configuration after the changes prescribed for production of 50.7 MW.

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After changes</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugarcane crushed/year</td>
<td>2 160 000</td>
<td>2 160 000</td>
<td>TCS</td>
</tr>
<tr>
<td>Sugarcane crushed/hour</td>
<td>500</td>
<td>500</td>
<td>TCH</td>
</tr>
<tr>
<td>Amount of bagasse produced</td>
<td>136.8</td>
<td>136.8</td>
<td>t/h</td>
</tr>
<tr>
<td>Bagasse burnt</td>
<td>130.3</td>
<td>130.3</td>
<td>t/h</td>
</tr>
<tr>
<td>Steam produced</td>
<td>293.8</td>
<td>295.7</td>
<td>t/h</td>
</tr>
<tr>
<td>Steam consumed in the process</td>
<td>400</td>
<td>300</td>
<td>kgs/tc</td>
</tr>
<tr>
<td>Steam pressure</td>
<td>65</td>
<td>100</td>
<td>bar(g)</td>
</tr>
<tr>
<td>Steam temperature</td>
<td>485</td>
<td>530</td>
<td>ºC</td>
</tr>
<tr>
<td>Flow of steam extracted at 1.5 bar(g)</td>
<td>210.3</td>
<td>170</td>
<td>t/h</td>
</tr>
<tr>
<td>Steam flow at the pressure-reducing valve</td>
<td>0</td>
<td>0</td>
<td>t/h</td>
</tr>
<tr>
<td>Steam flow for condensation turbogenerator</td>
<td>76.5</td>
<td>118.7</td>
<td>t/h</td>
</tr>
<tr>
<td>Total power produced</td>
<td>58.7</td>
<td>69.9</td>
<td>MW</td>
</tr>
<tr>
<td>Power consumed by the plant</td>
<td>18</td>
<td>19.2</td>
<td>MW</td>
</tr>
<tr>
<td>Net surplus power</td>
<td>40.7</td>
<td>50.7</td>
<td>MW</td>
</tr>
</tbody>
</table>
Figure 2 is a schematic representation (Olivério, 2008; 2009) of the first generation technology bioelectricity production scenario summarised in Table 8.

Second-generation technologies

The state-of-the-art mill makes use of the maximum energy embodied in juice and bagasse. However, the energy contained in vinasse and crop residues can also be utilised. Taking advantage of both sources is part of the second-generation technologies.

To make use of vinasse, an aerobic biodigestion system is required. Besides treatment of the mill effluents, it also generates biogas.

This technology is already available at a commercial sugar industry scale. The biogas generated must be pressurised and sent to burners installed in the biomass boiler.

This additional energy in the boiler will generate more steam, which will be used in the condensing turbine. By this means, surplus power will increase from 50.7 MW to 55.7 MW.

Let us consider now the use of 50% of the straw (harvest residue) as feedstock. Similar to biogas, this feedstock will be burnt in the boiler, generating more steam for the condensing turbine and, therefore, more surplus electricity.

Technologies and operational changes associated with the recovery of straw are currently still under development and are expected to be ready for commercial application in the near term. Multi-fuel boilers capable of burning bagasse, biogas and straw are already commercially available.

With the introduction of biogas and 50% of the crop residues, surplus power generation can reach 83.9 MW. Figure 3 is a schematic representation of second generation technology bioelectricity production (Olivério, 2008; 2009).
Technological trends in bioelectricity production

Third-generation technologies under development include bagasse and straw gasification for the production of synthesis gas to power advanced cycle bioelectricity plants. With the application of this technology, it will be possible to operate an integrated gas turbine combined cycle (IGCC) in the mills. In this cycle, the biogas produced from vinasse and the syngas from bagasse and straw will be used in the gas turbine, which drives the generator and produces surplus power. The gases that leave the gas turbine are directed to a heat recovery steam generator (HRSG). Steam generated in the HRSG goes to a steam turbogenerator configured similarly to the processes described earlier. After the development and availability of this technology in commercial scale, surplus power production can be as high as 110 MW. In this case, gasification of bagasse and 50% of crop residues are assumed; if 100% of the crop residues could be transported from the field to the mill to produce syngas, surplus power generation would be as high as 150 MW (Olivério, 2008; 2009).

A diagram of the third generation technology is shown in Figure 4 (Olivério2008; 2009), forecast for long term implementation.
Bioelectricity—a new business in sugarcane sector

With the new rules introduced by the Brazilian government and with the use of the technologies presented in this paper, large scale production of surplus power represents a new business for the sugar and ethanol mills.

With the technologies currently available, there is great flexibility for retrofits of the existing plants.

In new projects (Greenfield), the implementation of new technologies is much easier, because the mill is designed according to the concept of maximum use of the energy contained in sugarcane.

It is also important to emphasise that the payback for a retrofit in the existing plants is 4–5 years, depending on the technological solution chosen (Olivério, 2008; 2009).

A good way to evaluate the success of the bioelectricity program is the growing interest of the industry in the biomass energy auctions that have been promoted in Brazil. The amount of installed power generation capacity as a result of the Brazilian programs for production of energy from biomass is increasing, as can be seen in Table 9 (Olivério, 2008; 2009)

<table>
<thead>
<tr>
<th>Auctions</th>
<th>Contracted in auction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winner projects Nº</td>
<td>Installed MW</td>
</tr>
<tr>
<td>1st Auction of new energy</td>
<td>Dec.05</td>
</tr>
<tr>
<td>2nd Auction of new energy</td>
<td>Jun.06</td>
</tr>
<tr>
<td>3rd Auction of new energy</td>
<td>Oct.06</td>
</tr>
<tr>
<td>1st Auction of altern. sources</td>
<td>Jun.07</td>
</tr>
<tr>
<td>4th Auction of new energy</td>
<td>Aug.08</td>
</tr>
<tr>
<td>Total</td>
<td>61</td>
</tr>
</tbody>
</table>

REFERENCES


COGÉNÉRATION – UNE NOUVELLE SOURCE DE REVENUS POUR LES USINES A SUCRE ET D'ÉTHANOL

Ou

BIOELECTRICITY—UNE NOUVELLE ENTREPRISE

Par

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MOTS CLEFS: Cogénération, Bioelectricity,
Optimisation Énergétique, Surplus de Puissance, Énergie Moulin.

Résumé

LA COGENERATION, l'efficacité énergétique et la production d'électricité excédentaire sont des anciennes rubriques dans les usines de canne du Brésil. Toutefois, jusqu'en 2003, le soutien institutionnel et réglementaire n’existait pas, le gouvernement brésilien a alors décidé d'encourager et de réglementer la production d'électricité. Aujourd'hui, la production de bioelectricity dans les usines de canne et la vente d’électricité au réseau sont de plus en plus importantes. Le potentiel de bioelectricity dans l'industrie du sucre brésilienne atteint 1800 MW en 2007–2008. Pendant une vente aux enchères le 8 août 2008, l'agence brésilienne de l'énergie (Agence Nacional de Energia Elétrica – Aneel) a déterminé les règles d'appel d'offres, y compris le prix maximal à payer pour la bioelectricity comme énergie de réserve pour les 15 prochaines années, ce qui se traduit par une capacité installée totale de 2385 MW. Les projections pour 2020–21 prévoient que l'alimentation de la grille sera équivalente à 14 400 MW, et que les revenus générés par cette nouvelle entreprise seront comparables à la production de sucre brésilien. Ce scénario ouvre des opportunités pour les nouvelles technologies d'optimisation énergétique. Ce document est axé sur l'utilisation de la canne d'un point de vue énergétique pour (a) optimiser l'utilisation de l'énergie contenue dans la plante (b) pour réduire au minimum la consommation d'énergie par les usines de sucre et d'éthanol (c) pour intégrer la production d'électricité dans le production du sucre et de l'éthanol (d) pour maximiser la production d'électricité excédentaire. Des technologies nouvelles sont intégrées à l'usine pour améliorer le bilan énergétique: approche mécanique/électrique ou électro-hydraulique pour la conduite des moulins; fermentation a des concentrations d'éthanol plus fortes à l'aide de refroidisseurs pour permettre des températures plus basses; distillation combinée sous vide et pressurisée; utilisation de membrane pour la déshydratation; production de biogaz a partir de la vinaise et sont utilisation comme carburant; utilisation de la paille comme carburant; chaudières capables d’utiliser plusieurs carburants, à haute pression, température et d'efficacité élevée (120 bar(g), 530°C, 89% – LHV); turbogénérateur de condensation/extraction. Trois étapes hiérarchiques de la technologie sont présentées: usines de canne a sucre première génération, deuxième génération et troisième génération. L’usine Bioelectricity « dernier cri » est présentée et des innovations sont considérés pour la conception de l'usine de canne complète.
COGENERACIÓN – UNA NUEVA FUENTE DE INGRESOS PARA PLANTAS DE AZÚCAR Y ETANOL

o

BIOELECTRICIDAD – UN NUEVO NEGOCIO

Por

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PALABRAS CLAVE: Cogeneración, Bioelectricidad, Optimización Energética.

Resumen

COGENERACIÓN, eficiencia energética y producción de energía para la venta son temas antiguos en los ingenios brasileños. Sin embargo, no contaron con soporte institucional y regulatorio hasta 2003, cuando el gobierno brasileño decidió impulsar y regular la producción alternativa de producción de electricidad. A la fecha la producción de bioelectricidad en los ingenios y la venta de energía a la red son un nuevo negocio de rápido y sostenido crecimiento. La capacidad instalada de bioelectricidad en la industria azucarera brasileña alcanzó 1800 MW en 2007/08. En una licitación pública en Agosto 8, 2008 la Agencia Nacional de Energía Eléctrica determinó las reglas de comercialización, incluyendo el precio máximo a ser pagado por bioelectricidad como una reserva de energía por los próximos 15 años, lo que resultó en una capacidad total instalada de los ganadores de la licitación, de 2385 MW. Las proyecciones para 2020/21 anticipan que el suministro a la red será equivalente a un promedio de 14 400 MW, y que los ingresos netos generados con este nuevo negocio serán similares a los de la producción de azúcar de Brasil. Este escenario abre oportunidades para nuevas tecnologías de optimización energética. Este trabajo se enfoca sobre el uso de la caña desde un punto de vista energético y como (a) maximizar el uso de energía contenida en la caña (b) minimizar el consumo de energía de las plantas de azúcar y etanol; (c) integrar el proceso de producción de electricidad con el proceso de producción de azúcar y etanol; (d) maximizar la producción de energía exportable. Nuevas tecnologías se incorporan a las plantas para mejorar el balance energético: accionamientos electromecánicos con engranajes planetarios e inversores de frecuencia o accionamientos electrohidráulicos para a las unidades de molienda; fermentación a contenidos más altos de etanol usando chillers de absorción para permitir temperaturas más bajas; combinación de destilación presurizada y en vacío; uso de membranas para deshidratación; biogás a partir de vinaza y su uso como combustible; uso de los residuos de cosecha como combustible; calderas multicomestible con altas temperaturas, presiones y eficiencias (120 bar$\text{(g)}$, 530ºC, 89% – PCI); turbogeneradores de extracción condensación. Se presentan tres etapas jerárquicas de tecnología: ingenios de primera, segunda y tercera generación. Se presenta el ingenio ‘estado del arte’ en bioelectricidad y las innovaciones son consideradas en el diseño del ingenio completo.
ETHANOL DEHYDRATION SYSTEM BY SIFTEK™ POLYMERIC MEMBRANE

By

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KEYWORDS: Ethanol Dehydration, Polymeric Membrane, Vapour Permeation, Pervapouration.

Abstract
ETHANOL is very important renewable energy to Brazil and several companies are improving their technologies by developing processes to increase the benefits of ethanol compared to fossil sources. The Siftek™ polymeric membrane is a technology that can save between 35 and 70% of energy when compared with conventional processes. The first pilot plant (Tiverton, Canada) operated dehydrating grain-based ethanol from 80–90 wt% ethanol to 99.2 wt%, showing the good performance of the membrane system. With the goal of testing the system in a commercial capacity, a second plant (Chatham, Canada) was built and operated with success, drying grain-based ethanol from 40–60 wt% ethanol to 99.5 wt%. To demonstrate this technology to Brazilian ethanol producers, a third demonstration unit was built and operated in ethanol plants from sugarcane. The results confirmed the excellent selectivity of the membrane system to water, dehydrating ethanol from 85–93 wt% to higher then 99.5 wt%, with lower energy consumption and preserving product quality.

Introduction
Ethanol is becoming every day a more popular and important bio-energy source for liquid fuels. In Brazil, its production from sugarcane has reached 22 billion litres in 2007/08, with anhydrous ethanol corresponding to 35% of the total (Unica, 2009).

This result has been achieved by the popularity of the flexible fuel cars and the mixture of ethanol with gasoline that currently represents 25% of the Brazilian ethanol market.

However, it is even more important to have an alternative energy source that has a positive energy balance and the membrane technology can contribute very well to reach this goal.

Recently, polymeric membranes have received much attention because of their excellent performance in gas and vapour separation, especially in separation of water from organic vapour mixtures in industrial processes, which include water-ethanol systems (Huang et al., 2003a).

Considering that there are several kinds of polymeric membranes in existence, the one to be used in the industrial process should be solvent resistant and have high permeability (Huang et al., 2003b).

The Siftek™ polymeric membrane has these properties and was designed specifically for ethanol-water separation with a higher selectivity for water over ethanol.

Distillation and dehydration are responsible for the largest fraction of energy use in ethanol production.

The technology discussed in this paper has the potential to reduce this energy consumption between 35 and 70% when compared with conventional technology, like molecular sieve or extractive dehydration with cyclohexane (Côté et al., 2007).
**Siftek™ membrane and system**

Siftek™ is a hydrophilic polymer membrane that can be used to dehydrate ethanol in the vapour phase in a continuous process illustrated in Figure 1. The ethanol-water vapour mixture is fed in one side of the module containing thousands of fine polymeric hollow fibre membranes.

The mixture travels in the parallel channels and the water vapour is drawn through the dense polymer membrane (while the ethanol is rejected) under a driving force established by a vacuum on the shell side of the module. The hollow fibre membranes are assembled into a shell to form a module. These modules are arranged in series-parallel in a system (Côté *et al.*, 2007).

![Fig. 1—Conceptual operation of membrane.](image1)

The membrane is used under rigorous conditions and has exceptional thermal, mechanical and solvent resistance properties. It is a proprietary polymer formulation based on polyimide that provides a high flux and water/ethanol selectivity.

The main components of the system are shown in Figure 2. The dehydration system is an integrated solution of the membrane with conventional technology. The pre-treatment heats the ethanol-water vapour mixture about 5°C above the dew point. Typically, the operating temperature and pressure is between 100–110°C and 125–170 kPa absolute.

![Fig. 2—Components of the Siftek™ membrane system.](image2)

In both stages a vacuum is applied on the permeate side of the membrane to create a driving force for water permeation. A lower vacuum is required in Stage 2 because of the lower water concentration after Stage 1 (less than 5%). Typical values for vacuum are 10–30 kPa for Stage 1 and 2–10 kPa for Stage 2. A vacuum pump is normally used to reach a lower vacuum and to evacuate non-condensable gases.

The membrane system is fully integrated with the ethanol plant from a mass and energy point of view. There are many installation options available to maximise the benefits of a membrane.

**Tiverton Field pilot unit**

The first polymeric membrane technology demonstration was done at the Greenfield Ethanol plant in Tiverton, Ontario, Canada from August 2006. The goal of the field pilot unit was to
test the membrane under field conditions. The pilot unit was equipped with a single module (the first generation of commercial modules).

The pilot plant was fed with an ethanol-water mixture from a rectification column with concentration varying between 80 and 90 wt% ethanol. The unit, with capacity of 1.0 m$^3$/day, operated at an absolute pressure of 120–140 kPa and temperature of 105 to 115°C producing fuel-grade ethanol. Figure 3 shows the results of a continuous operation over 200 days producing ethanol to an average of 99.2 wt%.

![Figure 3—Result in Tiverton field unit.](image)

**Chatham Field demonstration unit**

The second demonstration was conducted in a bigger capacity plant (8 m$^3$/day) with two membrane stages, which was installed at Greenfield Ethanol plant in Chatham, Ontario, Canada, with start up in October 2008. The objective of this field demonstration unit was to test a two-stage commercial scale membrane system fully integrated with an industrial grain-based ethanol plant.

A simplified process flow diagram is shown in Figure 4. The demonstration unit was fed with an ethanol-water vapour mixture from the beer column with concentration between 40–60 wt% ethanol.

![Figure 4—Process flow diagram of Chatham demonstration unit.](image)
The plant operated with vapour fed at an absolute pressure of 170–175 kPa, and temperature of 105–110°C. Before feeding the membrane, the flow passed through a filter to avoid any liquid or solid in the membrane.

The ethanol concentration was increased to around 90 wt% through the first stage membranes and further to the final concentration through the second stage membranes.

Figure 5 shows the results of a continuous operation, producing ethanol with concentration between 99.2 and 99.8 wt%.

This demonstration unit was integrated with the industrial plant and involved recompression of the first stage permeate from an absolute pressure of 40 kPa to an absolute pressure of 250 kPa that was re-injected in the rectification column, reducing the fresh steam load.

The permeate from the second stage with a low concentration of ethanol was recycled to the beer column for ethanol recovery.

**Dedini demonstration unit**

The third demonstration unit was built in Brazil with the objective to demonstrate the Siftek™ technology for ethanol production from sugarcane.

The plant was designed with flexibility to process three types of feed: 45 wt% ethanol from the beer column, 93 wt% from the rectification column, and 85 wt% from molecular sieve recycle (Figure 6).

This last condition is a very interesting application because it allows an increase of the anhydrous ethanol production in the distillery (this alternative is described further in this paper).

The Dedini demonstration unit (Figure 7) operates with two membrane stages (one membrane in each stage) and has a capacity of 5 m³/day.

The industrial performance tests were carried out at Costa Pinto Sugar Mill in Piracicaba-SP (2008) and São Martinho Sugar Mill in Pradópolis-SP (2009) (Gabardo Filho, 2008, 2009).
The plant operated with vapour fed at an absolute pressure around 160 kPa, and temperature of 115°C. Before feeding the membrane, the flow passed through a knock pot to avoid any liquid or solid in the membrane and in the super-heated system.

A molecular sieve unit (MSU) produces a recycle flow with ethanol concentration between 50 and 70% during its operation and this flow needs to be reprocessed in the distillation (the lower value is the result of the dilution in the liquid ring vacuum pump used). One alternative to the membrane system is to dehydrate this recycle flow to increase the anhydrous production, avoiding the re-processing step. The first operating condition was to process the MSU recycle in a distillation process to increase the concentration to around 85% and then dehydrate it in the membrane system. The second operating condition was dehydration of the hydrous ethanol (93 wt%) from the rectification column producing anhydrous ethanol.
The third operating condition was to process the ethanol-water flow from the beer column with concentration around 45 wt% producing ethanol 99.5 wt% (to be done in November 2009).

Figure 8 shows the results of the dehydration process from the MSU recycle by membrane system (operating condition 1).

The feed concentration oscillated between 76 and 93 wt% ethanol, according to the operation of the industrial distillation column.

The system assimilated this variation very well, providing a flexibility feature for the Siftek™ membrane that is not found in other, conventional technology.

The two black bars in Figure 8 represent the leak of feed from the distillery during rain periods.

The permeate flow, with low ethanol concentration, was sent to be recovered in the distillation process. It represented a recycle between 2 and 2.5% of the feed ethanol, compared with around 15 – 30% from molecular sieve.

Other parameters measured were the acetic acidity and conductivity. Figure 9 shows the behaviour of the acidity during operation.

It shows a small increase of around 2 mg/L in the acidity of the product. This increase is the result of the water reduction in the product and consequent concentration of the organic compounds.

It is more an indicative parameter that confirms the higher selectivity of the membrane to water compared to organics. Although the acidity is increasing, it remains lower than the specification (30 mg/L).

Figure 10 shows the conductivity in the feed and in the product, resulting in an average reduction of 55%, helping to meet the product quality specification value (500 μS/m).
In the second operating condition, the system was fed with 93.0 wt% hydrous ethanol in liquid phase. Figure 11 shows the results where it is possible to see again the stability in product quality, with average of 99.65% wt% ethanol.
Application of the membrane technology

There are some industrial applications where the Siftek™ Technology can be integrated in a bio-ethanol plant. Figure 12 shows the membrane application like a dehydration plant, replacing conventional technology like molecular sieve or dehydration via extractive distillation with cyclohexane in greenfield plants. The Siftek™ membrane is a product that has the advantage of no chemical contamination and high energy saving. The membrane steam consumption is around 0.41 kg steam/L of product, resulting in an energy saving around 35% when compared with MSU (consumption of 0.65 kg steam/L) and around 70% when compared with a cyclohexane dehydration process (1.55 kg steam/L).

Another industrial application of the Siftek™ technology is the treatment of the MSU recycle stream. In a conventional plant, a MSU is regenerated by applying vacuum sweeping with purified ethanol. This stream, containing 50–70 wt% ethanol, is recycled to the rectification column, representing a recycling of about 15–30% of the purified ethanol produced by the plant, resulting in an additional energy consumption for re-purification.

The use of a membrane system for dehydration of the MSU recycle stream can save around 15% energy, with a consumption of 0.55 kg steam/L, and debottlenecking the plant by freeing up capacity in the rectification column and MSU. If these processes are limiting, plant production could be increased by around 20%. This process flow diagram is shown in Figure 13.
Conclusions

Considering the excellent results obtained in the demonstration plants and in the industrial design, the conclusions are:

- The Siftek™ system is a polymeric membrane that can be used to dehydrate ethanol in vapour phase because of its high selectivity of water over ethanol, with benefits of no contamination in the product and lower energy consumption.
- The three demonstration plants showed a high membrane performance in water removal, producing ethanol in a continuous process with concentration higher than 99.5 wt% ethanol.
- The Dedini system showed a high stability in quality product with an average of 99.65 wt% ethanol, with a system flexibility to assimilate variation in the feed concentration.
- Recirculation of ethanol is minimised.
- The membrane technology can be installed in new plants with lower energy consumption, saving around 35% of energy when compared with molecular sieve technology and around 70% when compared with extractive distillation by cyclohexane.
- When used to treat the MSU recycle stream, the membrane results in a reduction of around 15% in energy consumption with increased production capacity of 20%.

Acknowledgments

This project is a partnership between Dedini S/A Indústrias de Base and Vaperma Inc. During the operation in Brazil, the system was supported by Cosan Group and São Martinho Group, two of the biggest sugarcane processors in the world.

REFERENCES


SYSTÈME DE DÉSHYDRATATION D'ÉTHANOL PAR DES MEMBRANES POLYMÉRIQUES SIFTEK™

Par

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MOTS-CLEFS: Éthanol, Déshydratation, Membranes Polymériques, Vapeur Imprégnation, Pervaporation.

Résumé
L’ETHANOL est une énergie renouvelable importante au Brésil et plusieurs sociétés améliorent leurs technologies afin d’accroître les avantages de l’éthanol par rapport aux combustibles fossiles. Les membranes polymériques Siftek™ donnent une technologie qui peut économiser entre 35 et 70% d'énergie par rapport aux processus classiques. La première usine pilote (Tiverton, Canada) a exploité une déshydratation d’éthanol de grain de 80–90% d’éthanol à 99.2 % (masse), démontrant la bonne performance des membranes. Dans le but de tester le système à titre commercial, une deuxième usine (Chatham, Canada) a été construite et exploitée avec succès, utilisant l’éthanol de grain de 40 à 60% d'éthanol à 99.5% (masse). Pour démontrer cette technologie aux producteurs d'éthanol brésiliens, un troisième appareil de démonstration a été construit et exploité dans les usines d'éthanol a partir de la canne. Les résultats ont confirmés l'excellente sélectivité du système de membrane pour l'eau; une déshydratation de 85–93% d'éthanol a été augmentée a 99.5%, avec une faible consommation d'énergie et en préservant la qualité du produit.
SISTEMA DE DESHIDRATACIÓN DE ETANOL CON MEMBRANA POLÍMÉRICA SIFTEK™

Por

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PALABRAS CLAVE: Deshidratación de Etanol,
Membrana Polimérica, Permeabilidad al Vapor, Pervaporación.

Resumen

EL ETANOL es energía renovable muy importante para Brasil y varias compañías están mejorando sus tecnologías desarrollando procesos para incrementar los beneficios del etanol comparado con las fuentes fósiles. La membrana polimérica Siftek™ es una tecnología que puede ahorrar entre 35 y 70% de la energía cuando se la compara con procesos convencionales. La primera planta piloto (Tiverton, Canadá) operó deshidratando etanol de granos desde 80–90% en peso hasta 99.2% en peso, evidenciando el buen desempeño del sistema de membrana. Con la meta de probar el sistema a capacidades comerciales, una segunda planta (Chatham, Canadá) fue construida y probada exitosamente, deshidratando etanol de granos desde 40–60 % en peso hasta 99.5% en peso. Para demostrar esta tecnología a los productores de etanol brasileños se construyó una tercera planta piloto y se operó en las plantas de alcohol a partir de caña. Los resultados confirmaron la excelente selectividad del sistema de membrana al agua, deshidratando desde 85–93% en peso a 99.5%, con un menor consumo de energía y preservando la calidad del producto.
MODELLING THE EFFECT OF THE SRI SWIRL SPREADER BAGASSE COMBUSTION SYSTEM ON FURNACE OPERATION

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KEYWORDS: Boilers, Bagasse, Furnace, Combustion, Swirl.

Abstract

CONVENTIONAL pneumatic bagasse spreader systems with a plane air jet to feed bagasse into sugar mill boilers have been widely used for over forty years. Being relatively simple and reliable, conventional spreaders have served the cane sugar industry well. However, they do have some significant deficiencies. Firstly, at high bagasse moisture contents, there is usually a significant build up of fuel on the grate which limits steam output and can cause combustion instability. The pressure excursions arising from combustion instability can cause significant damage to the boiler. Secondly, by inspecting the flame in the furnace through any small ports available, it is clear that the flame produced is concentrated towards the back part of the furnace. A significant portion of the furnace volume is underutilised. The swirl spreader addresses the issue of an underutilised furnace volume by spinning the bagasse as it enters the boiler, achieving a better spread of fuel over the furnace grate and reduced deposition of unburnt material. Current swirl spreader installations have made it possible to increase boiler steam output by up to 10% and make the boilers more tolerant of high moisture content bagasse. Further improvements in performance are possible through the use of hot air at the swirl spreader. The Computational Fluid Dynamics (CFD) code FURNACE was used to compare swirl spreaders to conventional spreaders, both cases using hot air, based on modelling the effect on furnace operation. The modelling predicted that the swirl spreaders achieve a more uniform temperature profile in the furnace, with smaller hotter and colder regions, and with the flame located closer to the grate. Lower peak and average gas temperatures and velocities at the furnace exit and convention bank tube inlet were predicted with swirl spreader operation due to the predicted increase in furnace heat absorption.

Introduction

Conventional pneumatic bagasse spreader systems (Dixon and Jorgensen, 1988) with a plane air jet to feed bagasse into sugar mill boilers have been widely used for over forty years. Being relatively simple and reliable, the conventional spreaders have served the cane sugar industry well. However, they do have some significant deficiencies. Firstly, at high bagasse moisture contents, there is usually a significant build up of fuel on the grate which limits steam output and can cause combustion instability. The pressure excursions arising from combustion instability can cause significant damage to the boiler. Secondly, by inspecting the flame in the furnace through any small ports available, it is clear that the flame produced is concentrated towards the back part of the furnace. A significant portion of the furnace volume is underutilised. Previous computer modelling has supported this observation and predicted that a significant increase in heat transfer would occur if the volume in the furnace was better utilised (Dixon and Plaza, 1995). Improved heat transfer in the furnace will result in improved overall boiler steam output and boiler efficiency and, in the longer term, the development of a smaller, cheaper boiler station.
The swirl spreader addresses the issue of an underutilised furnace volume by spinning the bagasse as it enters the boiler, achieving a better spread of fuel over the furnace grate and reduced deposition of unburnt material. Mann et al. (2004) described the history of its development, including the operation of a large sugar mill boiler (MCR 200 t/h) at Proserpine Mill using swirl spreaders of Mark III design. Since that time, relatively small modifications by Proserpine Mill staff have resolved a wear problem, resulting in the current Mark IV design. Observations from boilers where swirl spreaders have been retrofitted have shown that swirl spreaders (using cold air) can increase boiler steam output by up to 10% and make boilers more tolerant of high moisture content bagasse.

It is believed that the use of swirl spreaders with hot air will result in further improvements in boiler performance. Such measurements are not available. Computer modelling can be used to gain some insight into the operation of a furnace with such an installation. Previous work (Woodfield et al., 1997, 1998; Mann et al., 2004) demonstrated that the Computational Fluid Dynamics (CFD) code FURNACE (Boyd and Kent, 1986) successfully predicts general trends and patterns in a furnace, including gas temperature and velocity distributions. This poster paper uses FURNACE to compare the gas temperature and velocity predictions for the Proserpine No. 4 boiler furnace operating with conventional spreaders and with swirl spreaders.

**Predicted results for furnace operation**

The Proserpine No. 4 boiler was modelled with conventional spreaders and with swirl spreaders. Both types of spreaders were positioned on the same centre line. The simulated swirl spreader air temperature was 230°C. In order to compare only the swirl spreader to the conventional spreader, all air for both alternatives was simulated to enter the furnace at this temperature, with the total amount of bagasse and air entering the furnace being identical for both alternatives. The modelling was carried out for operation at a high steam load (210 t/h). A description of the furnace locations referred to in the discussion of the predictions is shown in Figure 1. The results of the simulations are shown in Figure 2, Figure 3 and Figure 4, which respectively show a gas temperature side view near the middle of the furnace, a gas temperature plan view halfway up between the grate and the bottom of the furnace exit baffle, and a gas velocity side view near the middle of the furnace.
Inspection of the gas temperatures shows that, relative to the conventional spreaders, operation with the swirl spreaders results in a larger more even flame which occupies a greater volume within the furnace, with smaller areas of both hotter and colder gases.

The gas velocities with the swirl spreader operation are predicted to have less recirculation downwards at the front top of the furnace, with a more even gas distribution out of the furnace. Peak gas velocities at the furnace exit baffle and at the tubes at the inlet to the convection bank are predicted to be lower for operation with swirl spreaders.

The use of swirl spreaders with hot air instead of conventional spreaders with secondary air at the same temperature is predicted to significantly improve the utilisation of the available furnace volume.
Conclusions

Computer modelling has been used to gain some insight into the operation of a furnace with a swirl spreader installation using hot air, relative to a conventional spreader installation using secondary air at the same temperature. Boiler operation with swirl spreaders is predicted to result in a larger more even flame which occupies more of the volume of the furnace, with smaller areas of both hotter and colder gases, resulting in a significant improvement in the utilisation of the available furnace volume. Peak gas velocities at the furnace exit baffle and at the tubes at the inlet to the convection bank are predicted to be lower for operation with the swirl spreaders due to the predicted increase in furnace heat absorption.

Acknowledgments

Tom Stoneham and Brian Dinnie at Proserpine Mill are acknowledged for resolving a wear problem in the swirl spreader.

REFERENCES


MODELLISATION DES EFFETS DU SYSTEME SWIRL SRI POUR LA DISTRIBUTION DE LA BAGASSE AUX CHAUDIERES

Par

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MOTS CLEFS: Chaudière, Bagasse, Combustion, Foyer, Swirl.

Résumé
Le système conventionnel pour l’alimentation de la bagasse aux chaudières a été utilisé pendant plus de 40 ans. Ce système est bien établi et son opération est relativement aisé, mais il présente des désavantages. Une forte humidité de la bagasse, par exemple, cause des problèmes d’alimentation qui réduisent le débit de vapeur et déstabilisent l’opération de la chaudière. La pression devient instable ce qui peut causer des dégâts. On a aussi trouvé que les flammes sont concentrées à l’arrière du fourneau, réduisant le volume utilisé. Le système Swirl évite ce problème en distribuant la bagasse d’une façon efficiente et en réduisant les dépôts de matériel non brûlé. Les systèmes Swirl en opération ont permis une amélioration de 10% au débit de vapeur et facilitent l’opération avec de la bagasse plus humide. On peut aussi améliorer la performance en utilisant de l’air chaud avec le système Swirl. On s’est servi du logiciel FURNACE en «Computational Fluid Dynamics, CFD» pour comparer le système Swirl au système conventionnel, avec de l’air chaud dans les deux cas. Le model montre que le système Swirl donne une température plus uniforme au foyer, avec moins de régions plus froides ou chaudes; la flamme est située plus près de la grille. Le modèle indique que Swirl réduit la fourchette de la température et de la vitesse des gaz à la sortie du foyer et aux tubes, grâce à une absorption de chaleur plus efficace.
MODELAMIENTO DEL EFECTO DEL SISTEMA DE COMBUSTIÓN BASADO EN EL DISPERSOR DE TORBELLINO PARA COMBUSTION DE BAGAZO SRI EN LA OPERACION DEL HORNO DE CALDERA

Por
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PALABRAS CLAVE: Calderas, Bagazo, Horno, Combustión, Torbellino.

Resumen

LOS SISTEMAS convencionales neumáticos para el lanzamiento de bagazo con chorro plano de aire para alimentar el bagazo en calderas de ingenios han sido ampliamente usado por cerca de 40 años. Relativamente simples y confiables los lanzadores neumáticos han servido bien a la industria. Sin embargo tienen deficiencias significativas. Primero, con contenidos altos de humedad de bagazo hay amontonamiento de bagazo en la parrilla que limita la generación de vapor y puede causar inestabilidad de la combustión. Las variaciones de presión debidas a la inestabilidad de combustión pueden generar significativo deterioro de la caldera. En segundo lugar, al inspeccionar el hogo por las mirillas es evidente que las llamas se concentran hacia la parte trasera del hogar, dejando una porción importante del volumen del mismo subutilizada. El lanzador de torbellino aborda el tema haciendo girar en torbellino la corriente de bagazo en su entrada a la caldera, logrando una mejor dispersión sobre la parrilla y una menor deposición en la misma de material inquemado. El lanzador de torbellino logra un mejoramiento adicional con el uso de aire caliente en el lanzador. El código FURNACE basado en Dinámica Computacional de Fluidos (CFD) fue utilizado para comparar los lanzadores convencionales y el tipo torbellino, en ambos casos usando aire caliente, y predecir el comportamiento de la operación del horno. Los modelos predicen que los lanzadores de torbellino logran una temperatura más uniforme en el hogar con zonas muy frías o muy calientes más pequeñas y con una llama localizada más cerca de la parrilla. Se obtuvieron predicciones de los valores de las temperaturas y velocidades del gas a la salida del hogar y a la entrada del banco convectivo, tanto pico como promedio, más bajos con el lanzador de torbellino, debido al incremento de la absorción de calor en el hogar.
ENVIRONMENTALLY FRIENDLY LUBRICANTS FOR MILL BRASSES

By

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KEYWORDS: Brass, Lubricant, Mill, Viscosity.

Abstract

IN SPITE of environmental, safety and hygiene pressures to eradicate their use, large quantities of asphaltic oils are still used for the lubrication of mill brasses in sugarcane mills. Since about 1980, people have been encouraged to find a solution to the contamination resulting from the use of asphaltic oils and, at the same time, have started to identify significant related costs. Lubricant technology has advanced, introducing new products to provide an effective solution to the contamination problem. This paper shows the evolution of technology from asphaltic oils to very high viscosity oils. These high viscosity oils cause very low environmental impact, are used in small quantities, and are considered biodegradable, with low-toxicity. Some products are considered food-grade.

Introduction

In spite of environmental, safety and hygiene pressures to eradicate their use, large quantities of asphaltic oils are still used for lubrication of mill brasses in sugarcane mills. ‘Mill brasses’ is the common name for the large plain bearings (journal bearings) of sugarcane mills.

The mill brass is one of the mill components with the greatest mechanical stress, since it is subjected to:

- Very high load: 5 to 10 MPa.
- Very high operating temperature: up to 100°C.
- Very low speed: from 4 to 7 r/min.

These operating conditions constitute a specific ‘lubrication regime’ and, in this situation, wear by friction is potentially important. It is necessary to know the lubrication regime to design the best lubricant for the application. These regimes can be identified in the Striebeck/Hersey curve, developed by Striebeck (1902) and Hersey (1914). The Striebeck/Hersey curve determines the coefficient of friction as a function of viscosity (Z), velocity (N) and load (P).

Figure 1 shows that, for a velocity close to 0 and with high loads, the viscosity of the lubricant ‘Z’ is the parameter that must increase in order to ideally let us get away from the regime of ‘boundary lubrication’. However, ‘hydrodynamic’ lubrication, in which there is no metal-to-metal contact between the roll shaft and the bearing, cannot be reached. The possibility of providing effective flow of sufficient lubricant is, in practice, between 100 and 200 times inferior to what is required. Consequently, the lubrication regime of mill brasses remains ‘boundary lubrication’ (Hargreaves, 1984).

In addition to the actual operating conditions of mill brasses, as defined by the ZN/P expression, high temperatures of the order of 100°C can also be developed in the roll shaft-bearing interface. Contaminants such as water, cane juice and bagasse add to the problem, and should be counteracted with design of proper mechanical protection arrangements, alignment and adjustment between the roll shaft and the bearing.
Requirements for designing better lubricants

The design of better lubricants primarily requires that ZN/P is as high as possible. Therefore, viscosity Z will be as high as possible. Viscosity, however, is not the only important condition. Other requirements must be taken into account, given the need to improve the environmental, safety and hygiene performance of mill brass lubricants and to extend the useful life of equipment. The guidelines for the design of a suitable lubricant should be as follows:

**Tribologic requirements of lubricant**
1. Very high viscosity at 100°C
2. Must provide metal adherence for longer residence time in the roll shaft-bearing interface
3. Must avoid or minimise water, cane juice or bagasse input
4. Enough thermal stability at high operating temperature
5. In ‘boundary lubrication’ regime, must have EP capacity necessary to prevent micro-welding when the lubricating layer is thin (four-ball test, ASTM D 2783, weld load ≥ 620 kg).

**Distribution requirements of lubricant**
6. Must be fluid so as to enable its handling and pumping in centralised lubrication systems
7. Its structure must be homogenous, without getting dispersed, in view of repeated pressurisation-release cycles

**Chemical resistance requirements of lubricant**
8. Must not attack valve and pump seals
9. Must withstand contamination by water
10. Must withstand contamination by cane juice

![Figure 1 - Coefficient of friction as a function of viscosity (Strubeck, 1902)](image-url)
Requirements for environment and security and hygiene

11. Must enable lubrication with very low application quantity; 10 times less than asphalts.
12. Must be clear and non-irritating
13. Must be highly biodegradable according to environmental international standards
14. Must have low toxicity
15. Must credit food grade certifications, H1 if required
16. Must derive from renewable resources

Evolution of lubricants for mill brasses

After asphaltic oils, there have been two main evolutions in lubricant types: graphite greases with solid lubricants (graphite) that were originally used for lubrication of open gears in mine and cement industries and, in recent years, very high viscosity oils.

Table 1 shows the performance of the different technologies of lubricants for mill brasses. The numbers in the table relate to the 16 lubricant requirements (reproduced below). The white box signifies poor lubrication, the yellow box signifies good lubrication and the green box signifies excellent lubrication.

Table 1—fulfilled requirements of mill brasses of lubricant.

<table>
<thead>
<tr>
<th>Year</th>
<th>1980s decade</th>
<th>1990s decade</th>
<th>2000s decade</th>
<th>At present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphaltic oils</td>
<td>1 2 3 4</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Graphite greases or European type</td>
<td>5 6 7 8</td>
<td>5 6 7 8</td>
<td>5 6 7 8</td>
<td>5 6 7 8</td>
</tr>
<tr>
<td>Very high viscosity oils</td>
<td>9 10 11 12</td>
<td>9 10 11 12</td>
<td>9 10 11 12</td>
<td>9 10 11 12</td>
</tr>
<tr>
<td>Very high viscosity oils BIODEGRADABLE</td>
<td>13 14 15 16</td>
<td>13 14 15 16</td>
<td>13 14 15 16</td>
<td>13 14 15 16</td>
</tr>
<tr>
<td>Very high viscosity oils BIOBASED</td>
<td>17 18 19 20</td>
<td>17 18 19 20</td>
<td>17 18 19 20</td>
<td>17 18 19 20</td>
</tr>
</tbody>
</table>

Theoretical calculation of oil viscosity for a mill brass

Assumptions

A mill top roll brass has been analysed for a mill crushing between 4500 and 5000 tonnes of cane per day and the following configuration:

- Diameter main mill brass: 480 mm
- Effective length of brass: 550 mm
- Mean diameter of roller: 1000 mm
- Length of roller: 2000 mm
- Diameter of hydraulic cylinder: 356 mm

Table 2 relates the top roll hydraulic pressure to the pressure on the top roll brass.

Table 2—Typical field operation conditions of mill brasses.

<table>
<thead>
<tr>
<th>Hydraulic pressure (MPa)</th>
<th>Pressure onto main mill brasses (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>5.9</td>
</tr>
<tr>
<td>18</td>
<td>5.3</td>
</tr>
<tr>
<td>16</td>
<td>4.7</td>
</tr>
<tr>
<td>15</td>
<td>4.4</td>
</tr>
<tr>
<td>14</td>
<td>4.2</td>
</tr>
</tbody>
</table>
Lubrication parameters
The following parameters should be considered when determining the lubricant viscosity:
1. Lubricant viscosity at rating temperature
2. Pressure between contact surfaces
3. Rotational speed
4. Separation between surfaces (clearance)
5. Materials used (very important for effective lubrication)
6. Quality degree of surfaces.
7. \(\text{l/d ratio (bearing length/bearing diameter)}\)

It is quite complex to relate all these terms, and so a simplified formula has been adopted, (Martinet, 1985)

\[ K = \mu \times n \times 10^8 / P \]

\(\mu\): viscosity (kg.s/m²)
\(n\): rotational speed (r.p.s)
\(P\): specific pressure in the main bearings (kg f/m²)

For the purposes of this specific study we will distinguish three types of lubrication:
- Boundary lubrication: metallic rubbing between the journal-brass.
- Mixed lubrication: in some parts, friction is metallic; in others, it is fluid by means of lubricant
- Hydrodynamic lubrication: lubricant layer is installed on the whole mill brass surface.

The method to determine if our case tends to fall in the last mode is by evaluating K value
If \(K < 5\), hydrodynamic lubrication is not possible.
If \(K \geq 5\), superficial termination will be with 0.005 mm roughness and antifriction material.
If \(K \geq 15\), rectified journal and bronze bearing.

Thus, in our case we look for oil for which the K value must be \(\geq 15\)

Comparison: Asphaltic oil - Very high viscosity biodegradable oil
Table 3 shows K values for different values of speed, temperature and pressure in main mill brasses for an asphaltic oil. Note that the unit of viscosity (kg*seg/m²) is the same as that used in the above formula (kg.s/m²). Table 4 shows K values for a very high viscosity biodegradable oil. It is clear that the K values are considerably higher for the very high viscosity oil than for the asphaltic oil.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>40°C</th>
<th>50°C</th>
<th>60°C</th>
<th>70°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z (kg*seg/m²)</td>
<td>0.20</td>
<td>0.13</td>
<td>0.08</td>
<td>0.06</td>
</tr>
<tr>
<td>n (r/min.)</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>K</td>
<td>3.15</td>
<td>3.97</td>
<td>4.77</td>
<td>2.05</td>
</tr>
<tr>
<td></td>
<td>2.94</td>
<td>3.71</td>
<td>4.46</td>
<td>1.91</td>
</tr>
<tr>
<td></td>
<td>2.75</td>
<td>3.48</td>
<td>4.17</td>
<td>1.79</td>
</tr>
<tr>
<td></td>
<td>2.45</td>
<td>3.09</td>
<td>3.71</td>
<td>1.59</td>
</tr>
<tr>
<td></td>
<td>2.21</td>
<td>2.78</td>
<td>3.34</td>
<td>1.43</td>
</tr>
</tbody>
</table>

(Kg*seg/m²) by 9807 ≈ cSt
Table 4—K value for very high viscosity biodegradable oil lubricated mill brass.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>40°C</th>
<th>50°C</th>
<th>60°C</th>
<th>70°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z (kg·seg/m²)</td>
<td>1.61</td>
<td>1.04</td>
<td>0.70</td>
<td>0.34</td>
</tr>
<tr>
<td>n (r/min.)</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Hydraulic pressure</td>
<td>140</td>
<td>6.76</td>
<td>8.11</td>
<td>150</td>
</tr>
<tr>
<td>Pressure onto brass</td>
<td>419</td>
<td>219</td>
<td>448</td>
<td>711</td>
</tr>
<tr>
<td>K</td>
<td>25.35</td>
<td>31.99</td>
<td>38.40</td>
<td>4.98</td>
</tr>
<tr>
<td></td>
<td>23.68</td>
<td>29.89</td>
<td>35.88</td>
<td>4.27</td>
</tr>
<tr>
<td></td>
<td>22.17</td>
<td>27.98</td>
<td>33.59</td>
<td>4.00</td>
</tr>
<tr>
<td></td>
<td>19.70</td>
<td>24.87</td>
<td>29.85</td>
<td>3.87</td>
</tr>
<tr>
<td></td>
<td>17.76</td>
<td>22.42</td>
<td>26.91</td>
<td>3.72</td>
</tr>
</tbody>
</table>

(Kg·seg/m²) by 9807 = cSt

Case study

Lubricant performance was measured in a sugarcane mill with a milling tandem consisting of five 1981 mm mills crushing 12 000 tonnes of cane per day. The mill brasses were lubricated with 16 500 cSt @40°C very high viscosity biodegradable oil. The lubricant consumption is shown in Figure 2. The average lubricant consumption was 10 litres per day (0.9 g per tonne of cane). This lubricant consumption was 80% less than is typical of black or asphaltic oils.

The operating temperature was kept stable, as shown in Figures 3 and 4 for the first and final mills respectively.
At the end of the first season of operation, the brasses and the roll shafts was both in good condition (Figure 5).

With the new lubricant, there was minimal spillage of lubricant on the factory floor (Figure 6). The absence of spills improves workplace safety.
Conclusion

Asphaltic oil and graphite greases cannot fulfil the requirements of mill brass lubrication. The high K values required can, however, be achieved with very high viscosity oil. The very high viscosity oil causes very low environmental impact, as much less lubricant is required and is considered biodegradable, with low-toxicity.

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LUBRIFIANTS POUR COUSSINETS DE MOULINS
SANS EFFETS NOCIFS POUR L’ENVIRONNEMENT

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MOTS-CLES: Coussinets, Lubrifiant,
Moulin, Viscosité.

Résumé
EN DEPIT de l'environnement, de la sécurité et de l'hygiène, de grandes quantités d'huiles bitumineuses sont toujours utilisées pour la lubrification des coussinets de moulin dans les usines à canne. Depuis 1980, le personnel a été encouragé à trouver une solution à la contamination résultant de l'utilisation d'huiles bitumineuses et, en même temps, on a commencé à identifier les coûts associés à cette contamination. La technologie de lubrifiant a progressée et on a lancé de nouveaux produits afin de fournir une solution efficace aux problèmes de contamination. Ce papier montre l'évolution de la technologie d'huiles bitumineuses vers des huiles de très haute viscosité. Ces huiles de haute viscosité provoquent un impact environnemental très faible, sont utilisées en petites quantités et sont considérées comme biodégradables, avec une faible toxicité. Certains produits sont même considérés acceptables comme aliments.

LUBRICANTES AMBIENTALMENTE AMIGABLES
PARA BRONES DE MOLINOS

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PALABRAS CLAVE: Bronce, Lubricantes,
Molino, Viscosidad.

Abstract
A PESAR de las presiones ambientales, de higiene y de seguridad para erradicar su uso, se siguen empleando grandes cantidades de aceites asfálticos para la lubricación de cojinetes de bronce en molinos de caña. Alrededor de 1980 se incentivó la búsqueda de soluciones a la contaminación causada por los aceites asfálticos y al mismo tiempo se comenzó a identificar los costos asociados al tema. La tecnología de lubricantes ha avanzado, introduciendo nuevos productos para proveer una solución efectiva al problema. Este trabajo trata sobre la evolución de la tecnología desde los aceites asfálticos hasta los aceites de muy alta viscosidad. Estos aceites causan un muy bajo impacto ambiental ores cantidades, y se consideran biodegradables, con baja toxicidad. Algunos de estos productos son considerados de grado alimenticio.
FERRITIC STAINLESS STEEL AISI 439
FOR THE SUGAR INDUSTRY

By

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Abstract

The objective of this technical paper is to identify the best material for tubes in evaporators, heaters and vacuum pans of cane sugar mills. Several cane and beet sugar processing plants were studied to analyse production conditions. The main considerations in the selection of tube materials were corrosion resistance and its effect on the durability of the tube, mechanical strength and its effect of the structure of the heat exchanger, thermal conductivity and its effect on the amount of energy required, surface finish and its effect on scaling and cleaning. Several materials were tested. AISI 439 ferritic stainless steel gave the best results.

Introduction

Today, major requirements at a sugar processing plant are to reduce equipment and energy costs. One of the main processes at a sugar plant is the evaporation system, which removes water from the cane juice. This system uses a lot of energy, and involves heat-transfer through tubes providing heat-transfer areas amounting to tens of thousands of square metres. The price of tubes directly affects the equipment-cost factor, while the quality of the installed tubes affects energy consumption.

This paper reports on the materials and procedures used for tubes in sugar processing plants all around the world and compares them with AISI 439 produced by Arcelor Mittal.

Analysis and results

The requirement

Figure 1 shows a schematic of a conventional tubular heat exchanger. Shells are usually made of carbon steel, as are the intermediate plates or tube-end plates. The tubes are either expansion-swaged into the plates to ensure mechanical closure and sealing or are held by O-ring seals. In the latter case, tube surface finish is a decisive factor in achieving leak-free sealing.

Fig. 1—A tubular heat exchanger.
Heat flow in a tube

The following equation describes heat transfer through a tube.

\[ R = \frac{e}{\lambda S} \]

where \( \lambda \) is thermal conductivity, \( S \) is heat transfer area and \( e \) is thickness.

To achieve the best thermal flow, there must be the best possible conductivity. The determining factors are:

- the film of water on the tubes (condensation)
- the thickness of the tubes
- the thickness of the scale (variable during the season)
- the conductivity of the material (\( \lambda \))

**How can these factors be improved?**

**Condensation**

This factor is difficult to reduce. By its very nature, heat transfer creates considerable condensation.

**Tube thickness**

Currently, thickness is usually from 1.5 to 2 mm depending on the material used. With ferritic grades of stainless steel, thicknesses are from 1.2 to 1.5 mm (depending on the length of the infrastructure of the evaporators) and from 1.5 to 2 mm for boilers.

**Scaling thickness**

Scale accumulation can have various causes:

*The surface finish of the tube’s internal wall*

Limiting the roughness of the internal surface of the tube to around 0.4 \( \mu \)m is a major factor in limiting scale accumulation when juice is flowing through a tube.

*The weld surface inside the tube*

Depending on the process used, there may be variable weld-bead build up and consequent variable surface smoothness.

For heat exchanger applications, ArcelorMittal uses laser welding for AISI 439 stainless steel (Figure 2), which ensures a highly consistent weld and a very smooth surface.

![Fig. 2—Micrography of a laser weld.](image)
Grade selection factors

The chemical composition of stainless steels

Table 1 compares two materials used in evaporator tubes.

Table 1—Chemical composition of AISI 304 and AISI 439.

<table>
<thead>
<tr>
<th>Stainless steel family</th>
<th>Norms</th>
<th>C%</th>
<th>Ni%</th>
<th>Cr%</th>
<th>Ti%</th>
<th>N%</th>
</tr>
</thead>
<tbody>
<tr>
<td>AISI 439</td>
<td>Ferritic</td>
<td>0.020</td>
<td>17.5–18.5</td>
<td>0.5 max</td>
<td>0.010</td>
<td></td>
</tr>
<tr>
<td>AISI 304</td>
<td>Austenitic</td>
<td>0.045</td>
<td>8–9</td>
<td>18–19</td>
<td></td>
<td></td>
</tr>
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Thermal conductivity

Table 2 shows the thermal conductivity of four tube materials. This parameter should be as high as possible, to ensure the least loss of heat. The higher this factor, the less the process consumes energy and the lower are the production costs. Copper seems the obvious choice but its price and the thicknesses used are a handicap. Carbon steel, which has been very widely used in the past, is now used less because of its poor corrosion resistance and the consequent need for thick gauges. Also, its rough surface finish encourages scaling. Austenitic stainless steels have poor thermal conductivity. AISI 439 ferritic stainless steel is the best technical and financial compromise.

Table 2—Thermal conductivity levels for commonly-used materials.

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<th>Materials</th>
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</tr>
</thead>
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</table>

The physical properties of the materials:

Apart from thermal conductivity requirements, there are other material properties necessary for the evaporator tube application. Tubes:

- are held to the plates by swaging (require ease of deformation)
- pass through intermediate plates (require mechanical strength)
- are subjected to vibration (require mechanical strength)
- are subjected to chemical attack from sugar juice (require corrosion resistance)
- are cleaned by various procedures (require corrosion resistance)

Properties such as the coefficient of linear expansion, strength and corrosion resistance are important. Table 3 presents the physical properties of four different tube materials.

The coefficient of linear expansion has become more important as tubes have become longer. With grade AISI 439, the tubes stay straight at high temperature although tubes are mechanically terminated at both ends.

The absence of bending lessens the rubbing of tubes against each other and reduces premature wear in the intermediate-plate area.

The mechanical properties of AISI 439 are more favourable than those of carbon steel, allowing thinner gauges (i.e. reduced weight) and improved heat flow. In addition, AISI 439 shows excellent stability within the usual operational temperatures (Figure 3).

It can be seen that the mechanical characteristics are relatively stable at temperatures found in sugar processing (up to 200°C).
Table 3—Comparison of different grades (ArcelorMittal, 1993).

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<th>Parameters</th>
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</tr>
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<tbody>
<tr>
<td></td>
<td>439</td>
</tr>
<tr>
<td>Density</td>
<td>7.70</td>
</tr>
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<td>Young's modulus</td>
<td>20 800</td>
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<td>Tensile strength (MPa)</td>
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</tr>
<tr>
<td>Hardness (HRB)</td>
<td>83</td>
</tr>
<tr>
<td>Linear expansion (10^{-6}/°C)</td>
<td>9.8</td>
</tr>
</tbody>
</table>

Corrosion resistance: 0 = bad / 100 = very good

| Pitting corrosion     | 80  | 80  | 95     | 20           |
| Generalised corrosion | 100 | 100 | 100    | 60           |
| Stress corrosion cracking | 100 | 20  | 20     | 100          |

Fig 3—Changes in mechanical characteristics of grade AISI 439 depending on temperature (ArcelorMittal, 2009).

**Corrosion**

The corrosion properties of four tube materials are also shown in Table 3. The corrosion properties were rated by ArcelorMittal with a scale from 0 (poor corrosion resistance) to 100 (good resistance), based on the performance of the different materials in corrosion tests.

With the grade AISI 439, the corrosion resistance level is very good.

**Cleaning recommendations for AISI 439**

The cleaning of AISI 439 stainless steel tubes in evaporators was examined in tests with KEBO France. The best solution is to use a caustic solution and to clean by high pressure water or mechanical brushing.
Tube life

Since 1974, AISI 439 stainless steel tubes have been installed in many cane and beet sugar refineries in Europe, Africa and South East Asia. Their expected service life is about 20 years in evaporators\(^1\) and 30 years in vacuum pans\(^2\).

Financial factors

The absence of nickel in AISI 439’s chemical composition means that this grade is much less affected by speculation on the global money markets. Consequently, it is possible to:

- Offer a product with qualities identical or superior to AISI 304 or copper, at a lower price (10–15% less expensive than AISI 304, depending on the current nickel price);
- Offer longer price-validity periods, thanks to the relative stability of the price of chromium.

A financial analysis was conducted to compare the different types of tubes. The analysis was conducted over a 20 year operating cycle, corresponding to the expected life of the AISI 439 tubes.

For each material, an operating cost was determined. The operating cost included the purchase price of the tubes, the cost of cleaning (frequency, chemical products used, workforce required), and the lifespan of the tubes.

The results are shown in Figure 4.

---

![Operating cost based on 20 years](image_url)

Fig. 4—Calculated operating costs for different materials.

The overall cost of the AISI 439 stainless steel is lowest. AISI 304 has a higher purchase price. The cost of carbon steel is lower in terms of purchase price per tonne but the thicker gauge (2.5 mm instead of 1.2 mm, for example) reduces this direct-cost benefit.

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\(^1\)AISI 439 tubes used in evaporators in Zambia (Zambia Sugar plc.), Philippines (Central Azucarera San Antonio), Guadeloupe (Garde), La Réunion (Bois Rouge, )

\(^2\)AISI 439 tubes used in vacuum pans in Mauritius (Savannah, Medine, F.U.E.L, FivesCail continuous vacuum pans), Colombia (Incauca), Philippines (Cotabato), Thailand (Mitr Phu).
Conclusions

This study showed that AISI 439 grade stainless steel has advantages in all the following key factors in a ‘sugar-processing evaporation’ application:

- Thermal conductivity (30% better than an austenitic grade)
- Surface finish
- Mechanical properties
- Corrosion resistance
- The price of the material

REFERENCES


ACIER INOX FERRITIQUE AISI 439
POUR L'INDUSTRIE SUCRIÈRE

Par

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Bruno.Meyer@ArcelorMittal.com

MOTS-CLEFS: Acier Inoxydable 439, Ferrritique,
Tubes, Échangeur de Chaleur, Économies d'Énergie.

Résumé

L'OBJECTIF de ce document technique est d'identifier le meilleur matériau pour tubes d’évaporateurs, de réchauffeurs et de cuites des usines a sucre. On a étudié les conditions de production dans plusieurs usines de canne et de betterave. Les principaux éléments à prendre en compte dans le choix des matériaux pour les tubes étaient; résistance à la corrosion et son effet sur la durabilité du tube; résistance mécanique et son effet sur la structure de l'échangeur de chaleur; conductivité thermique et son effet sur le quantité d'énergie nécessaire; état de la surface et son effet sur l’encrassement et le nettoyage. Plusieurs matériaux ont été testés. L’acier inoxydable ferritique AISI 439 a donné les meilleurs résultats.
ACERO INOXIDABLE FERRÍTICO AISI 439
PARA LA INDUSTRIA AZUCARERA

Por

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Bruno.meyer@arcelormittal.com

PALABRAS CLAVE : Acero Inoxidable 439, Ferrítico,
Tubos, Intercambiador de Calor, Ahorro Energético.

Resumen

El objetivo de este artículo técnico es identificar el mejor material para tubos de evaporadores, calentadores y tachos de vacío de los ingenios azucareros. Se estudiaron varias plantas de procesamiento de remolacha y caña para analizar sus condiciones de producción. Las principales consideraciones en la selección de materiales de tubos fueron: resistencia a la corrosión y su efecto en la durabilidad del tubo; resistencia mecánica y su efecto en la estructura del intercambiador de calor; conductividad térmica y su efecto en la cantidad de energía requerida; acabado superficial y su efecto en incrustación y limpieza. Se probaron varios materiales. El acero inoxidable ferrítico AISI 439 dio los mejores resultados.
FERRITIC STAINLESS STEEL AISI 439
FOR THE SUGAR INDUSTRY

By

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Bruno.meyer@arcelormittal.com

KEYWORDS: 439 stainless Steel, Ferritic,

Abstract
The objective of this technical paper is to identify the best material for tubes in evaporators, heaters and vacuum pans of cane sugar mills. Several cane and beet sugar processing plants were studied to analyse production conditions. The main considerations in the selection of tube materials were corrosion resistance and its effect on the durability of the tube, mechanical strength and its effect of the structure of the heat exchanger, thermal conductivity and its effect on the amount of energy required, surface finish and its effect on scaling and cleaning. Several materials were tested. AISI 439 ferritic stainless steel gave the best results.

Introduction
Today, major requirements at a sugar processing plant are to reduce equipment and energy costs. One of the main processes at a sugar plant is the evaporation system, which removes water from the cane juice. This system uses a lot of energy, and involves heat-transfer through tubes providing heat-transfer areas amounting to tens of thousands of square metres. The price of tubes directly affects the equipment-cost factor, while the quality of the installed tubes affects energy consumption.

This paper reports on the materials and procedures used for tubes in sugar processing plants all around the world and compares them with AISI 439 produced by Arcelor Mittal.

Analysis and results
The requirement
Figure 1 shows a schematic of a conventional tubular heat exchanger. Shells are usually made of carbon steel, as are the intermediate plates or tube-end plates. The tubes are either expansion-swaged into the plates to ensure mechanical closure and sealing or are held by O-ring seals. In the latter case, tube surface finish is a decisive factor in achieving leak-free sealing.

Fig. 1—A tubular heat exchanger.
Heat flow in a tube

The following equation describes heat transfer through a tube.

\[ R = \frac{e}{\lambda S} \]

where \( \lambda \) is thermal conductivity, \( S \) is heat transfer area and \( e \) is thickness.

To achieve the best thermal flow, there must be the best possible conductivity. The determining factors are:

- the film of water on the tubes (condensation)
- the thickness of the tubes
- the thickness of the scale (variable during the season)
- the conductivity of the material (\( \lambda \))

**How can these factors be improved?**

**Condensation**

This factor is difficult to reduce. By its very nature, heat transfer creates considerable condensation.

**Tube thickness**

Currently, thickness is usually from 1.5 to 2 mm depending on the material used. With ferritic grades of stainless steel, thicknesses are from 1.2 to 1.5 mm (depending on the length of the infrastructure of the evaporators) and from 1.5 to 2 mm for boilers.

**Scaling thickness**

Scale accumulation can have various causes:

- *The surface finish of the tube’s internal wall*

  Limiting the roughness of the internal surface of the tube to around 0.4 µm is a major factor in limiting scale accumulation when juice is flowing through a tube.

- *The weld surface inside the tube*

  Depending on the process used, there may be variable weld-bead build up and consequent variable surface smoothness.

For heat exchanger applications, ArcelorMittal uses laser welding for AISI 439 stainless steel (Figure 2), which ensures a highly consistent weld and a very smooth surface.

![Fig. 2—Micrography of a laser weld.](image)
Grade selection factors

The chemical composition of stainless steels

Table 1 compares two materials used in evaporator tubes.

<table>
<thead>
<tr>
<th>Stainless steel family</th>
<th>Norms</th>
<th>C%</th>
<th>Ni%</th>
<th>Cr%</th>
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<tbody>
<tr>
<td>AISI 439 Ferritic</td>
<td>AISI 439/1.4510</td>
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Thermal conductivity

Table 2 shows the thermal conductivity of four tube materials. This parameter should be as high as possible, to ensure the least loss of heat. The higher this factor, the less the process consumes energy and the lower are the production costs. Copper seems the obvious choice but its price and the thicknesses used are a handicap. Carbon steel, which has been very widely used in the past, is now used less because of its poor corrosion resistance and the consequent need for thick gauges. Also, its rough surface finish encourages scaling. Austenitic stainless steels have poor thermal conductivity. AISI 439 ferritic stainless steel is the best technical and financial compromise.

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![Operating cost based on 20 years](image)

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ACERO INOXIDABLE FERRÍTICO AISI 439 PARA LA INDUSTRÍA AZUCARERA

Por

B. MEYER

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PALABRAS CLAVE : Acero Inoxidable 439, Ferrítico, Tubos, Intercambiador de Calor, Ahorro Energético.

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EL OBJETIVO de este artículo técnico es identificar el mejor material para tubos de evaporadores, calentadores y tachos de vacío de los ingenios azucareros. Se estudiaron varias plantas de procesamiento de remolacha y caña para analizar sus condiciones de producción. Las principales consideraciones en la selección de materiales de tubos fueron: resistencia a la corrosión y su efecto en la durabilidad del tubo; resistencia mecánica y su efecto en la estructura del intercambiador de calor; conductividad térmica y su efecto en la cantidad de energía requerida; acabado superficial y su efecto en incrustación y limpieza. Se probaron varios materiales. El acero inoxidable ferrítico AISI 439 dio los mejores resultados.
WATER PRODUCTION PLANT

By


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KEYWORDS: Water, Ethanol and Sugar Plants, Stillage.

Abstract

FRESH water is becoming one of the most important natural resources in the world. It is fundamental to human beings, for their own consumption, in industries, agricultural irrigation, electrical power production, and also in leisure and amusement activities. For industries, the availability of fresh water may represent a decisive factor in choosing the location of a new enterprise. In the case of Brazilian sugar and ethanol production, sugarcane culture traditionally does not use irrigation, which is an important factor from the environmental viewpoint, because it uses less fresh water, and avoids the entrainment of nutrients and agricultural toxic residues, and soil losses. In sugar and ethanol production, according to average data for the State of São Paulo in 2005, water consumption was 21 m$^3$ of water/tonne of sugarcane (180 litres per litre of ethanol), and intake of 1.83 m$^3$ of water/tonne of sugarcane (nearly 22 litres per litre of ethanol). The increasing demands of fresh water consumption and the shortage of this resource on a worldwide level is a concern to several sectors of society, as they are becoming more critical, demanding more responsible attitudes from companies, while the latter endeavour to follow a sustainable development policy to consolidate their companies and their products.

Introduction

Fresh water is a very precious asset and, as time passes, it becomes scarcer. One cannot imagine life without water. In an industrial society, the need for intensive food production has accelerated the consumption of this resource. Associated with water consumption, large volumes of effluents are generated. The rational use of water has become a question of fundamental importance to the survival of humanity. Its turn, industry is a large water consumer.

For illustrative purposes, according to ABIQUI M, the Brazilian Chemical Association, the use of water in the beer industry is between 15 and 25 L/L beer; for gasoline manufacture, between 7 and 10 L/L gasoline; polyethylene around 231 L/kg polyethylene; paper pulp 300 to 800 L/kg paper pulp and fine paper 900 to 1000 L/kg paper. In the sugar and alcohol industry, water consumption has been reduced, as illustrated by the data in Table 1. Nevertheless, there is a large potential for reduction.

<table>
<thead>
<tr>
<th>Year uses (m$^3$/tc)</th>
<th>1990(1)</th>
<th>1997(2)</th>
<th>2005(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-take</td>
<td>5.6</td>
<td>5.07</td>
<td>1.83</td>
</tr>
<tr>
<td>Consumption</td>
<td>1.8</td>
<td>0.92</td>
<td>Not available</td>
</tr>
<tr>
<td>Disposal</td>
<td>3.8</td>
<td>4.15</td>
<td>Not available</td>
</tr>
</tbody>
</table>

(1) Data from the State water resources plan (‘PERH - Plano Estadual de Recursos Hídricos’) 1994/95.
(2) CTC Survey (Sugar Cane Technology Center), 34 sugar mills in the State of São Paulo.
(3) UNICA/ CTC Survey – (‘CTC - Centro de Tecnologia Canavieira’) in 2005.
As will be demonstrated in the course of this paper, there is an enormous potential in the sugar and alcohol industry for changing from being a water importer to becoming a water exporter.

To get an idea of the production volumes involved in Brazil’s sugar and alcohol sector, according to DATAGRO, the 325 plants in operation in the 2006/07 season processed 427 million tonnes of sugarcane, which were cultivated in an area of 5.3 million hectares (8.8% of the arable area in Brazil), producing 18 million cubic metres of bioethanol and 31 million tonnes of sugar. For the production of these volumes of sugar and alcohol, it was necessary to take around 768 million cubic metres of water (1.8 m$^3$/t cane) and around 214 million cubic metres of stillage (12 m$^3$/m$^3$ ethanol) and 17 million tonnes of filter cake (40 kg/t cane) were generated.

**Technological options**

**Conventional mill**

A traditional sugar mill normally takes water from rivers, wells and/or reservoirs in the magnitude of 1.0 and 2.0 m$^3$ of water per tonne of sugar cane processed. When also considering the amount of water contained in the cane, which is typically 70% of the cane mass, then the total amount of water available is 2530 kg/tonne of cane (Figure 1).

![Figure 1—Water balance in a traditional mill.](image)

Water exits the factory with various products such as finished goods like sugar and ethanol, but also with the filter cake, bagasse (130.21 kg/t cane) and stillage (570.14 kg/t cane). The biggest quantity evaporates during cooling of condensing water (1052.00 kg/t cane) and cane washing, where applied, consumes 694.52 kg/t cane. There are other smaller quantities required for floor washing, restrooms, canteens, etc.)

**Self-contained mill**

An important step would be minimizing or even bringing the need for in-take water to zero and only utilise the water available with the cane; Measures to be implemented are to replace cane washing with dry cleaning. The water balance for a self-contained mill is shown in Figure 2.
By using vapours from the last effect of the evaporators and the vacuum pans for heating purposes (mixed juice heaters) the quantity of condensing water reduces from 1052.00 kg/t cane to 136 kg/t cane.

Water savings can also be made through improved design of the fermentation process. The alcohol content in the beer can be increased from 9.0 to 12.0 vol. % with newer designs. The process can be operated at lower temperatures (less than 30°C).

Less steam is required at the distillation columns and the stillage quantity reduces from 10.0 kg/L ethanol to 6.0 to 7.0 kg/L ethanol, which is 291.00 kg/t cane instead of 570.14 kg/t cane.

The spent wash, from the bottom of the rectification column, can be used in various sectors of the plant for cleaning equipment with good results.

**Water exporting mill**

The final step in water preservation is to move to water generation in the ‘Hydro Mill Plus’ (Figure 3).

The use of process steam and alcohol vapours from the rectification column as heating media in an energy optimised process should be considered. Resulting vapours would be sent to the juice concentrators for fermentation.

Concentrated stillage mixed with filter cake, boiler soot and ash with addition of other nutrients results in an ‘organomineral biofertiliser’ (BIOFOM). It contains 4.66 kg water/t cane.

The result of these measures allows the export of some 290.71 kg water/t cane, which is about one third of the water introduced with the cane.

Utmost extraction of energy contained in the various condensates contributes to the overall energy balance of the factory resulting finally in increased production of exportable electricity.
In summary, the following are required:
- Use of condensates as imbibition water;
- In preparation of mixed juice for fermentation, utilisation of energy from cooling the clarified juice (heat exchange), flash vapours and vapour condensates;
- Washing filter cake with condensate;
- Applying multi-effect juice evaporation with vapour bleeding for distillation and heating purposes;
- Exhaust condensate to be returned as feed water to the boilers, minimising heat losses;
- Utilising last vapours for mixed juice heating;
- Depending on the proportion of juice for ethanol and the quantity of molasses, there may be no need for pre-concentration of clarified juice for ethanol;
- Sugar boiling only with vapour;
- Utilising heat exchangers with condensates and/or vapours throughout the process;
- Producing a fermented beer with the highest possible alcohol content;
- Using vapours from juice or stillage evaporation in distillation;
- Concentrating stillage to 60% solids using vapours from juice evaporation and alcohol distillation;
- Drying stillage and mixing it with filter cake and boiler soot and ash to obtain ‘organomineral fertiliser (BIOFOM)’;
- Heat the beer for distillation with heat exchangers;
- Recovering of all condensates.
It is recognised that reused water will require pre-treatment and increased operating costs to achieve it.

Progress and conclusions

Dedini has taken an important step towards economic, social and environmental sustainability of the Biosugar and Bioethanol plants and, in 2008, has launched self-sufficient water mills and Biowater - water production mills. These plants are self-sufficient in water, and do not demand external supply from water sources. The water in sugarcane alone is sufficient to meet the requirements of the internal processes of the plant.

The further development of this concept is the optimisation of this technology, so that the Biosugar and Bioethanol mill saves water from sugarcane than it will use in the internal process, and will thus be in a position to export BIOWATER as excess water for industrial use.

USINE DE PRODUCTION D'EAU

Par


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MOTS-CLEFS: L'Eau, Production d'Éthanol et de Sucre.

Résumé

L'EAU douce est devenue une des plus importantes ressources naturelles dans le monde. Elle est fondamentale pour l'homme, pour leur propre consommation, dans les industries, l'irrigation agricole, la production de l'alimentation et de l'électricité et également dans les activités de loisirs et d'amusement. Pour les industries, la disponibilité de l'eau douce peut représenter un facteur décisif dans le choix de l'emplacement d'une nouvelle entreprise. Dans le cas de la production de sucre et d'éthanol au Brésil, la culture de la canne traditionnellement n'utilise pas d'irrigation, qui est un facteur important du point de vue environnemental, parce qu'elle utilise moins d'eau douce, évite l'entraînement de nutriments, de résidus toxiques agricoles et les pertes de sol. Dans la production de sucre et d'éthanol, conformément à la moyennes de données pour l'état de São Paulo en 2005, la consommation d'eau était 21 m³ d'eau par tonne de canne (180 litres par litre d'éthanol) et un apport de 1,83 m³ d'eau par tonne de canne (près de 22 litres par litre d'éthanol). Une demande croissante de la consommation d'eau fraîche et la pénurie de cette ressource à un niveau mondial sont des préoccupations pour plusieurs secteurs de la société. Devenant de plus en plus critiques, ces problèmes exigent des attitudes plus responsables par les entreprises, tout en faisant des efforts pour suivre une politique de développement durable afin de consolider leurs produits et leurs existences.
PLANTA DE PRODUCCIÓN DE AGUA

Por

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PALABRAS CLAVE: Agua,
Plantas de Azúcar y Etanol, VInazas.

Resumen

El agua fresca se está convirtiendo en uno de los recursos naturales más importantes en el mundo. Es fundamental para los seres humanos, para su propio consumo, en industrias, irrigación agrícola, producción de energía eléctrica, y también para actividades de recreación. Para las industrias, la disponibilidad de agua fresca puede representar un factor decisivo en la escogencia de la ubicación de una nueva planta. En el caso de la producción brasileña de azúcar y etanol, el cultivo tradicional no usa irrigación, lo cual es un factor importante desde el punto de vista ambiental debido a que usa menos agua fresca y evita el arrastre de nutrientes y residuos agrícolas tóxicos así como las pérdidas de suelo. En la producción de azúcar y etanol, de acuerdo a datos promedio para el Estado de São Paulo en 2005, el consumo de agua fue de 21 m$^3$ de agua/tonelada de caña (180 litros por litro de etanol), y un gasto de 1.83 m$^3$ de agua/tonelada de caña (aproximadamente 22 litros por litro de etanol). La creciente demanda de consumo de agua fresca y la escasez de este recurso a nivel mundial son una preocupación para varios sectores de la sociedad, en la medida que asumen una posición crítica, demandando más actitudes responsables por parte de las compañías siguiendo una política de desarrollo sostenible para consolidar sus empresas y sus productos.
ENERGY CYCLE IN CANE SUGAR MILLS: CONTROL AND OPTIMISATION

By

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KEYWORDS: Cane Sugar Mill, Control, Optimisation, Energy Cycle.

Abstract

Energy has become one of the most sensitive costs in industry. Cane sugar production is no exception. Real time energy control systems (RETEC) are the ideal tools for cutting down generation and production costs, and also preventing downtime and expensive repair jobs, improving savings. Information so obtained can be used for predictive maintenance purposes. When the energy control model was fed with real time data (standard analysis available in the mill), information was processed instantly, showing steam generation and consumption data, the whole energy cycle. As the model improved, it gradually became a guideline for controlling the process, resulting in lower incidence of low steam pressure and improved sugar production processes. On the equipment side, analysis allowed modifications and tuning on the run. The system also enhanced training of operators and engineers. Obtained benefits are: developed energy control system helped achieve more stable milling, as a better quality of steam was generated; energy specific consumption reduced from 0.810 to 0.461 tonnes of steam per tonne of cane; auxiliary fuel was unnecessary; Savings obtained were almost 10% of sugar price; less stressed boiler operation resulted in reduced amount and intensity of repairs, generating a second stage benefit; developed model defined some new energy indexes, for better understanding and control of energy generation. The stack became clear as combustion improved, reducing emissions of CO₂ and CO. A factory can adopt RETEC in its own way and obtain significant savings in fuel and repairs and less air pollution.

Introduction

Energy costs have increased in recent years as a result of global warming, oil prices and environmental regulations. Bagasse is the preferred fuel option, reducing fuel costs for a mill.

Today many applications are available to add value to sugarcane processing. Trash and tops are also burned. Diversifying bagasse utilisation is becoming a new profitable business.

With green harvesting and proper milling of trash and other crop residues, more bagasse can be processed for other applications and less greenhouse gases are introduced to the atmosphere. The Kyoto Protocol has established conditions for this ‘green’ market.

This paper proposes five systems and technologies for improving energy efficiency.

Systems and technologies for improving energy efficiency

Combustion adjustment

The way to improve a boiler’s performance is to set all air and fuel controls in such a way that every dampener and valve responds to control with precision and repeatability to allow the best
possible operation, keeping combustion at its best efficiency at all possible generating loads. Flue gas analysers are used to determine the positions of air dampeners and fuel valves.

**Very low excess air combustion based on CO/O₂ control**

As bagasse and residuals vary in their oxygen demand, combustion control based on fuel characterisation does not allow very low excess air operation.

CO increases as oxygen content in flue gases diminishes. High CO content results in a significant energy loss as only 72% of carbon energy is liberated. O₂ and CO measurement are the basis of combustion control. Figure 1 shows an energy relation between O₂ and CO content in flue gases.

Very low excess air operation requires intelligent online O₂ and CO analysers to control combustion of fuels with different and variable air demand. Figure 2 shows the location of analysers inside a boiler.

![Fig. 1—CO, excess air and heat losses.](image)

![Fig. 2—O₂ and CO analysers inside a boiler.](image)
Post combustion process

Traditional processes burn up to 70% of pith, as small particles cannot be retained in the boiler’s furnace for enough time to be completely burned. Energy losses are high. Pith has 19.2 MJ/kg and long fibre 15.1 MJ/kg. As result of incomplete combustion, average caloric value drops from 17.4 to 14.2 MJ/kg.

Incinerating pith in a Heavy Fuel Oil (HFO) pilot flame increases the caloric value from 14.2 MJ/kg to 16.7 MJ/kg, providing 17.9% of additional heat.

Thermic reforming of bagasse

With properly set fluidised bed air, bagasse burning temperature can rise enough to convert lineal carbon chains into benzene rings, liberating some hydrogen atoms that burn at a much higher temperature inside the boiler’s furnace, increasing steam generating speed rate and capacity. It is shown as a temperature jump of about 300°C. The boiler’s efficiency is then improved.

Real Time Control (RETEC).

The RETEC operates with four different fuels: solid, viscous liquids, light liquids and gas; continuously reducing O₂ when steam consumption is stable until the CO maximum limit is achieved. Very low excess air operation, post combustion and reforming are integrated to RETEC.

The RETEC includes control algorithms for Post combustion and Thermic reforming processes.

The RETEC monitors and controls each boiler and the equipment using steam, advises when equipment requires maintenance before failure, preventing undesirable shut downs.

Analyses conducted once a month:
- Caloric values and elementary analysis of bagasse, large fibre and pith, other vegetable residue,
- Caloric value and elementary analysis of auxiliary fuel,
- Isokinetic analysis of flue gases

Analyses conducted each hour and required process data:
- Bagasse moisture content,
- Flue gases composition, and
- Fibre exiting factory (bagasse and/or fibre and/or pith).

Real time data:
- Cane entering mills;
- Flow, pressure and temperature fed to each boiler of generated steam and water; auxiliary fuel and air (primary and secondary);
- Flow, pressure and temperature of steam in: main; to each turbine; to juice heaters, pans, crystallisers, centrifuges, sugar dryers and others;
- Flow of sugar exiting dryers.

Energy ratios obtained from collected data are the basis of efficiency analysis and can explain cost variations:

CenM: Energy per milled cane, [kJ/tonne].
CenAz: Energy per produced sugar, [kJ/tonne].
Cesp: Generated steam per milled cane, [steam tonne/cane tonne].
EnVa: Fraction of energy converted to steam, [%].
VaAz: Generated steam per produced sugar, [steam tonne/sugar tonne].
CoM: Auxiliary fuel per milled cane, [litres/cane tonne].
CoAz: Auxiliary fuel per produced sugar, [litres/sugar tonne].

These ratios are to be analysis guidelines, either solving problems or improving processes, and helpful in understanding energy costs of each alternative.

Using an Energy Balance Board, engineers and operators can see at a glance energy inputs (fuels) and outputs (steam and losses) per source, and bagasse surplus (fibre or fibre plus pith). An example computer screen board is shown in Figure 3.

Using a Mass Balance Board, all fluids entering and exiting boilers, steam flow balance can be observed (Figure 4).
An application of the energy efficiency techniques

In Santa Clara cane sugar mill after Combustion Adjustment and Post Combustion System, excess air reduced to 20% (Figure 5) and achieved 94% pith burning. Efficiency improved dramatically.
Because of the increased efficiency, a bagasse surplus was achieved. Benefits of excess bagasse included starting the milling season with no auxiliary fuel, selling electricity to the grid; and providing bagasse to new biotechnology processes to obtain cellulose without chemicals.

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CYCLE ENERGETIQUE AUX MOULINS A CANNE:
CONTROL ET OPTIMISATION

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MOTS-CLEFS: Moulins, Contrôle, Optimisation, Cycle d'Énergie.

Résumé
L'ÉNERGIE est devenue un des coûts industriels importants et la production du sucre ne fait pas exception à la règle. Les systèmes de contrôle d'énergie en temps réel (RETEC) sont des outils pour réduire les coûts de génération et de production, et également pour éviter les interruptions de service et les réparations onéreuses, amélioration ainsi les économies. Les informations obtenues peuvent être utilisées à des fins de maintenance prédictive. Lorsque le modèle de contrôle d'énergie fonctionne avec des données en temps réel (analyses standards de l'usine), les informations sont traitées instantanément, montrant des données de production et la consommation de vapeur, donc le cycle entier d'énergie. Comme le modèle s'améliore, il permet le contrôle du processus: cela réduit les incidences de vapeur de basse pression et la production du sucre est meilleure. Pour l'équipement, l'analyse a permis des modifications. Le système a également amélioré la formation des opérateurs et ingénieurs. Les avantages obtenus sont les suivants: Un bon contrôle d'énergie, une opération stable aux moulins et une meilleure qualité de vapeur générée; la consommation spécifique d'énergie réduite de 0.810 à 0.461 tonnes de vapeur par tonne de canne; pas de carburant auxiliaire; économies de presque 10% du prix du sucre; chaudières moins stressées réduisant l'intensité des réparations, donc un deuxième avantage; le modèle a défini certains nouveaux indices d'énergie, pour mieux comprendre et contrôler la production d'énergie.; les gaz de cheminée sont devenus clairs grâce à la combustion améliorée, réduisant les émissions de CO₂ et CO. Une usine utilisant le RETEC peut obtenir d'importantes économies de carburant et de réparations et peut réduire la pollution de l'air.
CICLO ENERGÉTICO EN INGENIOS AZUCEREROS:
CONTROL Y OPTIMIZACIÓN

Por

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PALABRAS CLAVE: Ingenio Azucarero, Control, Optimización, Ciclo Energético.

Resumen

La energía se ha convertido en uno de los costos más sensibles en la industria. La producción de azúcar de caña no es la excepción. Los sistemas de control de energía en tiempo real (RETEC) son las herramientas ideales para recortar los costos de generación y producción, y también para prevenir paradas y costosos trabajos de reparación, mejorando el ahorro. La información obtenida puede ser usada para fines de mantenimiento predictivo. Cuando el modelo de control de energía se alimentó con datos de tiempo real (análisis estándar disponible en el ingenio), la información se procesó instantáneamente, mostrando datos de generación de vapor y consumo, el ciclo energético total. En la medida que el modelo se mejoró, se convirtió en una guía para el control del proceso, resultando en menor incidencia de eventos de baja presión y procesos mejorados de producción de azúcar. Por el lado del equipo, el análisis permitió modificaciones y sintonía sobre la marcha. El sistema permitió el mejoramiento del entrenamiento de operarios e ingenieros. Los beneficios obtenidos fueron: el sistema desarrollado para control de energía contribuyó a obtener una molienda más estable con una mejor calidad del vapor generado; el consumo específico de energía se redujo de 0.810 a 0.461 toneladas de vapor por tonelada de caña: no fue necesario el consumo de combustible auxiliar; los ahorros alcanzados fueron casi del 10% del precio del azúcar; la operación menos esforzada de las calderas representó menor cantidad e intensidad de reparaciones generando beneficios de segundo nivel; el modelo desarrollado definió algunos nuevos índices energéticos, para una mejor comprensión y control de la generación de energía; en la medida que la combustión mejoró se redujeron las emisiones de CO\textsubscript{2} y CO. Una fábrica puede adoptar RETEC a su manera y obtener ahorros significativos en combustibles y reparaciones con menor contaminación del aire.
GREEN CANE IMPACT ON SUGAR PROCESSING: ISSCT PROCESS WORKSHOP 2008

By

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KEYWORDS: Green Cane, Trash, Extraneous Matter, Losses, Workshop.

Abstract

The ISSCT Process Section workshop held in Réunion 20–23 October 2008 was attended by 51 delegates from 10 countries. The theme was Green cane impact on sugar processing. The workshop provided a valuable and timely opportunity to review and discuss the impact on factory operations and performance from a green cane supply that could include significant levels of trash. It was particularly relevant to those mills that were considering options to boost their biomass intake for increased co-generation capacity. Several of the speakers related their experiences with processing ‘whole of crop’ cane supplies through the factory. Speakers detailed the problems and increased losses that were incurred when processing cane with high trash levels. The consensus of the delegates was that the best scenario would involve a cane-cleaning plant at the factory so that only clean cane would be processed through the factory. The forum recommended that more research was required to address the issues of increased impurities in the process streams associated with high trash levels. Site visits to the two factories and a cane-delivery station were arranged as part of the workshop.

Introduction

The Process Section Workshop was held at the Hotel Mercure Créolia, Saint Denis, Réunion from 19 to 23 October 2008 and was hosted by CERF (Centre d’Essai de Recherche et de Formation).

The theme for the workshop was Green cane impact on sugar processing. The workshop provided a valuable and timely opportunity to review and discuss the impact on factory operations and performance from a green cane supply that could include significant levels of trash. It was particularly relevant to those mills that were considering options to boost their biomass intake for increased co-generation capacity.

It was attended by 51 delegates representing 10 countries including some delegates who had travelled from as far away as Brazil, Nicaragua and Japan. All of the organisational matters for the workshop were handled extremely well by CERF and, in particular, by Laurent Corcodel and Carmille Roussel.

Opening session

The opening session of the workshop included presentations by Jean-François Moser, President of CERF, and Laurent Corcodel.

Moser’s presentation provided an insight into the sugar industry in Réunion and its significant importance to the local economy. He described how infrastructure had been developed to allow water collected on the eastern side of the island to be transferred to the western side to irrigate the crops. A modernisation program had resulted in the closure of all but two mills. Cogeneration plants using both bagasse and coal were established at each factory and both had been upgraded to handle the full crop. Cane delivery stations were developed in several areas (mostly on old mill
sites) to allow farmers to deliver the cane to local collection points. Each load is sampled on arrival before being transferred to semi-trailers for transport to one of the mills.

Corcodel reviewed the performance of the cane sugar industry in Réunion since 1984. Some of the important changes to the industry have included:

- The sugar industry in Réunion was consolidated to two factories (Le Gol and Bois Rouge), each processing about 1 000 000 t per year between July and December and producing 100 000 t of raw sugar each;
- The cane crop comprises two main varieties: R570 (high trash) and R579 (self trashing);
- Each field can be ratooned up to nine times;
- All cane is harvested green and much of the trash is included with the cane supplied to the factories;
- Cane is delivered to one of 12 transfer stations or directly to one of the two factories;
- Only 10–30% is mechanically harvested;
- The true purity of the mixed juice ranges between 86 and 90;
- Ash % brix in mixed juice trends down from about 5% at the start of the milling season in July to less than 4% in December;
- Reducing sugars % brix range from about 3% in July to 3.5 to 4.0 in December; and
- Plant reliability has improved significantly over the 20-year period from about 12% downtime to an average of 4% breakdown rate in 2007.

Technical sessions

Session 1—Sugar losses in storage: green cane versus burnt cane

_Determination of sucrose loss in storage of green billet cane (Michael Saska, Stuart Goudeau, Irina Dinu and Mike Marquette. Presented by Rod Steindl)_

Tests measured sucrose loss during 24-hour storage of green billet cane. Several tests were also organised in a sugar factory where, in addition to the storage on the ground, some damage or loss of cane may be expected from handling the cane with front-end loaders. The mass loss of sucrose in storage of green billets of 24 hours or less was adequately represented by a linear model based on the length of time (hours) within three temperature ranges: <17°C, 17–27°C and >27°C, representing cold, moderate and warm conditions, respectively. The predicted relative sucrose change (tonnes of sucrose lost or gained for each 100 tonnes of initial sucrose per hour) in the three temperature ranges are 0.022 (gain), –0.017 (loss) and –0.323 (loss), respectively.

An analogous model applied to the cane weight loss during storage of green billet cane. The predicted relative cane weight loss (tonnes of cane per 100 tonnes initial per hour) in the three temperature ranges <17°C, 17–27°C and >27°C was 0.02, 0.02 and 0.26, respectively. The six factory cane yard tests broadly agreed with the conclusions from the pilot storage tests done at Audubon Sugar Institute, indicating that the cane and sucrose mass losses from handling the cane in the cane yard were relatively small compared with the losses from the enzymatic and microbial action within the stored cane.

It was uncertain whether the small sucrose gain predicted by their model for cold storage of green billets was related to enhanced activity of sucrose synthesising enzymes, or suppressed invertase activity in post-harvest cane as a reaction to low temperatures, or was an artefact of the experimental technique.

The financial impact of the sucrose loss predicted for storage of cane at high temperatures
(3.2% in 10 hours at over 27°C) is serious, and consideration should be given to improving through their design the natural or forced ventilation of cane wagons and piles, and to the scheduling of harvest and storage of cane.

### Cane deterioration: Comparison green cane versus burnt cane – Researching a green cane deterioration indicator (Camille Roussel, Arnaud Petit and Laurent Corcodel)

During 1990–1995, the Process Department of CERF compared cane deterioration of whole cane and burnt cane to find a criterion to gauge cane deterioration. Those studies showed that ethanol was a good criterion in burnt cane, but not in green cane. As cane is no longer burnt in Réunion, deterioration trials undertaken since 1995 have dealt only with green cane. Decreases in weight, sucrose content and purity mean that growers lose about €1/tonne of cane per day from post-harvest delays.

Biochemical measurements were undertaken during deterioration trials in 2005 and 2007. In 2005, aconitic acid ratio appeared to be a good indicator of deterioration. In 2007, other deterioration criteria were tested using chromatography (HPIC and HPLC) to measure organic acids, polyols, and amino acids. Of particular interest was 1-kestose, which increased linearly with post-harvest delays. Results showed also that citrate, alanine, proline, cysteine, isoleucine, and leucine correlated well with the post-harvest delay.

### NIR evaluation of the post-harvest deterioration of sugarcane quality (M. Ueno, E. Taira, Y. Kawamitsu, K. Kikuchi and Y. Komiya)

All Japanese sugarcane is harvested green, because burnt cane is not accepted by the mills. The trash is transported with the cane and separated at the factory. About 60% of the sugarcane is harvested manually. Mechanical harvesters include small machines that load billets into bags on the back of the harvester through to large machines that load directly into trucks. Manual harvesting requires considerable labour, is hard work, and 1–3 weeks is required to load the transport truck. Deterioration that occurs in this period results in sugar losses and deteriorated cane affects the milling process and lowers the efficiency of the mill.

To measure the quality of sugarcane for payment, a 5 kg sample of cane is collected by the core sampler from every vehicle at the entrance of each factory. These samples are fibrated and a near infrared spectrometer (NIR) is used to measure the pol in cane (PIC) as a quality index. If the mill staff can quickly and easily know the degree of deterioration, the information becomes very useful for process control. An NIR calibration equation to measure the ethanol content was investigated as an index of deterioration of cane. VIS/NIR absorbance spectra (570 to 1848 nm) were measured using an NIR instrument (Foss InfraXact), and the calibration equation for ethanol was developed by partial least squares (PLS) regression analysis. As a result of PLS regression, the values of $R^2$, standard error of calibration (SEC), and standard error of cross validation (SECV) were 0.908, 0.09%, and 0.11%, respectively. The developed calibration equation successfully measured the ethanol concentration of deteriorated cane with simultaneous measurement of PIC. Ethanol concentration was examined by the developed calibration equation for 0, 21, 28 and 36 days after harvesting. Although ethanol was not detected in fresh cane, ethanol content increased dramatically as the delay increased. Ethanol content of all sugarcane samples of 11 sugar mills in Okinawa Prefecture were calculated by the developed calibration equation. About 5% of all samples showed more than 1% ethanol content. It was concluded that the NIR method gave information of the sugarcane deterioration to support the operation of all sugar mills in Okinawa without any chemicals or apparatus.

### Session 2—Mill de-trashing equipment: Design, operation, optimisation

**Development of a prototype factory-based trash separation plant (Phil Hobson. Presented by Rod Steindl)**

Several sugarcane industries are actively seeking an efficient way of bringing the biomass to
the factory to increase the co-generation potential. As well, some countries have or are about to ban the burning of cane. This has increased the interest in trash separation plants located either at the factory or in centralised locations closer to the cane supply areas. This presentation discussed investigations by Sugar Research Institute (SRI) to separate the trash at the factory.

Trash left in the field after harvest constitutes a large, currently untapped source of available biomass. Harvesting the whole cane plant and subsequently separating the trash from the cane stalk in the cane supply entering the factory could potentially double the amount of fuel available for power generation. The Queensland Treasury (Office of Energy), Stanwell Corporation Ltd, and the NSW Sugar Milling Co-operative funded the development by SRI of a commercial scale prototype cane-cleaning plant. Funding by the Australian Greenhouse Office assisted with the installation of a fully commercial cane-cleaning plant at Condong Mill. Preliminary trials carried out at SRI in 2000 provided much of the basic information for the design of the prototype cleaning plant. Construction at Condong Mill of the prototype trash separation plant was completed by, and initial commissioning began, in early December 2000. Extensive testing and further development of the plant was continued through 2001. The performance testing program showed that the plant was able to achieve high levels of trash separation at low levels of cane loss (less than 1%), at commercial pour rates. Trials with an industry standard shredder indicated that the shredder could reduce the trash to approximate bagasse like consistency, but with a power requirement of about 12 kW/t of trash per hour. Conventional cyclone technology removed at least 99% of the air-borne trash that flowed from the cleaning chamber.

Cane field residues as supplementary boiler fuel (Kassiap Deepchand and A.F. Lau)

Cane field residues (CFR) consist of the dry cane trash and the green leaves left in the field after harvest and last for about 6 months of the year (June to Nov/Dec). CFR confers a certain number of agronomic advantages such as soil moisture conservation in dry areas, control of soil erosion and maintenance of soil organic matter, but it also imparts a number of disadvantages in that it harbours pests and affects cane re-growth especially in areas with high rainfall. Investment was made in a dry cane-cleaning plant with a capacity of 150 tonnes of whole cane per hour and operated next to a sugar factory. The concept was to reduce sugar loss in bagasse and minimise sugar manufacture difficulties due to the CFR adhering/brought together with cane while, at the same time, targeting the long term additional CFR recovery to increase fuel availability for power plants and thus displace coal. Difficulties were encountered in continuous operation of the plant due to a lack of a constant flow of cane and of an inefficient separation of the trash from the long cane. Subsequently, some modifications were made to the plant, but it could not run beyond 90 t/h, although an improvement in the separation process was noted.

An alternative approach of using CFR as an additional fuel to bagasse is being looked into, and the objective is to increase and extend electricity generation period from these resources by displacing coal. The total amount of CFR (which normally contains around 25% moisture depending on climatic conditions prevailing at harvest and in the subsequent days) is around 15 t/ha. The project aims to collect up to 50% of the CFR from the fields under ratoon crop and almost all the CFR from fields which are to be replanted after 7–8 year crop cycle. Whereas equipment for collection (windrowing and baling – square or cylindrical) and transport are available for industrial applications, those for debaling/shredding have still to be identified or developed for such applications. The emphasis on current R&D has thus been focused on this particular aspect. Analysis of naturally dried CFR shows that it has a moisture content of 9–11%. Its caloric value at 10% moisture is about 15 MJ/kg. Industrial-scale trials using existing conventional mills have shown that such naturally dried CFR can conveniently be burnt in existing boilers. However, in view of the fact that the naturally dried CFR has a relatively higher ash content (8%) compared to bagasse (2.5%), it is proposed that it will, after preparation, be mixed with bagasse in a proportion of up to 25%.
Preliminary estimates indicate that, if 30% of the CFR is collected, prepared and mixed with bagasse from an annual cane production of 5.0 million tonnes, it can potentially generate 250 GWh of electricity. This will replace 150 000 t of coal and avoid the generation of 400 000 t of CO$_2$ and 30 000 t of coal ash. In monetary terms, the foreign exchange saved will be US$30 million assuming a projected future coal price of US$200/t.

Session 3—Effects of trash on factory operations

Ledesma’s green cane project (Mario Rostagno, Carlos Bada, Federico Knauff, Miguel Ullivarrí, Juan Carlos Mirande and Rodolfo Dofonzo. Presented by Rod Steindl)

Ledesma, a cane sugar factory in Argentina, has recently seen a significant increase in mechanised harvesting of cane. In 2007, 85% of the cane was harvested mechanically. The progression to mechanised harvesting has seen the proportion of green cane delivered to the factory increase from 11% of the crop in 2002 to more than 50% in 2005. The proportion of green cane has remained static in the following years. As part of their effort to maintain factory efficiency and product quality, factory staff have undertaken a number of investigations to quantify the effects of the increased proportion of green cane in the raw sugar factory, refinery, distillery and on their energy production. During the 2005 season, trials were undertaken to determine the green cane effect on milling capacity, sugar losses and bagasse moisture. The results can be summarised as follows:

- Final bagasse moisture increased by 7.3%;
- There was an increased frequency in chute blockages along the milling tandem due to the extra trash;
- Pol loss in bagasse increased from 0.64% to 0.70%;
- Throughput capacity of the milling tandems decreased by 7%;
- Although the molasses % cane remained relatively steady at about 3.66, pol loss in molasses increased by 8%;
- Raw sugar colour increased by 10%; and
- Because of the higher starch content of the trash, the consumption of $\alpha$-amylase increased from 40 kg/day to 120 kg/day.

In the refinery, the consumption of chemicals such as decolorant, phosphoric acid and filter aid increased significantly. In the distillery, the total production of ethanol increased by 5.8% as a result of the higher sugar content in the molasses. However, the efficiency decreased to 79% because of the problems associated with the higher ash levels in the fermentation broth. The additional bagasse for combustion allowed the factory to reduce its consumption of supplementary fuel (natural gas).

New laws in São Paulo state and a new agreement between the state and the mills have started a green revolution in the Brazil sugarcane business. By 2014, the cane fields where the harvesters will be able to operate must be harvested as green cane. By 2017, all the cane fields will be harvested as green cane and cane fires will be eliminated.

This green revolution impacts on both the growing sector and the mills. The crop of green cane has a strong impact in the agriculture and industry areas. The challenges for the agricultural sector will include:

- Varieties that withstand the impact of cutter blades on harvesters;
- Effects of trash blanketing on ratooning ability and pest activity;
- Increasing the row spacing to 1.5 m;
- Changes to farm implements to better cultivate the soil and apply fertiliser through the trash blanket; and
• Adoption of 100% mechanical harvesting.

The impact on the factory processes will include:
• Increased impurity loading from the higher extraneous matter in the cane supply;
• Reduced milling throughput;
• Increased dirt loading in the bagasse going to the boilers;
• Potential for lower sugar quality;
• Higher costs for maintenance and chemicals; and
• Greater sugar losses in the mud and bagasse.

The option being favoured is to transport the cane and trash to the factory and separate the trash through dry cleaning plants. The cleaning plant is based on pneumatic separation of the trash followed by cleaning of the trash to remove soil and then shredding of the trash. However, the cane cleaning technology was still only in its infancy.

Clarification properties of stalk and trash tissues from U.S. sugarcane varieties (Gillian Eggleston and Michael Grisham. Presented by Barbara Muir)

The effect of the U.S. change from burnt to unburnt or green sugarcane harvesting on processing has not been fully characterised. Furthermore, the current trend to investigate sugarcane trash (leaves and tops) as biomass for the production of bioproducts has made the processing quality of trash more important.

Sugarcane whole-stalks were harvested from the first ratoon crop of five commercial sugarcane varieties (LCP85-384, HoCP96-540, L97-128, L99-226, and L99-233) with varying yield and harvest characteristics. Four replicated tissue samples of brown, dry leaves (BL), green leaves (GL), growing point region (GPR) or apical internodes, and stalk (S), were separated. Juice from each tissue type was clarified following a hot lime clarification process (operated by most U.S. factories). Only GPR and GL juices foamed on heating and followed the normal settling behaviour of global sugarcane juice, although GL was markedly slower than GPR. GPR juice was critical to clarification. S juice tended to ‘thin out’ rather than follow normal settling, and much more upward motion of flocs was observed. Most varietal variation in settling and clarified juice characteristics occurred for GL.

The quality and not the quantity of impurities in the different tissues affected the volume of mud produced. Tissue juice brix (% dissolved solids) had no relationship with the amount of mud produced. After 30 min settling, mud volume per unit tissue juice brix varied markedly among the tissues (S=1.09, BL=11.3, GPR=3.0, and GL=3.1 mL/brix). Heat transfer properties of tissue juice and CJ were described. Clarification was unable to remove all BL cellulosic particles. GL and BL increased colour, turbidity and suspended particles in the clarified juice with BL worse than GL. This would cause difficulty downstream in the factory boiling house and make the future attainment of Very Low Colour (VLC) raw sugar more difficult. Strategies to reduce the delivery of green and, especially, brown leaves to the factory need to be identified and implemented urgently.

The effects of extraneous matter on factory operations (Rod Steindl)

Several separate investigations that considered the effects of extraneous matter (tops, trash, roots and soil) on the composition of mixed juice and the downstream processes were summarised. The objectives in each case were to quantify the effects of green cane harvesting with increased levels of trash on factory throughput and sugar quality so that economic models could be developed. Although different methodologies were used, the outcomes were similar.

In the first investigation, estimates were determined for the composition of a cane stalk by separating the stalk into clean cane, trash, tops and top leaf components. The averaged values for a number of varieties were:
• Clean cane 81.2%;
• Trash 7.1%;
• Tops 6.1%; and
• Top leaf 5.6%.

It must be accepted that these quantities depend on many factors and can only be used as a guide.

In laboratory trials, composite samples of clean cane and added tops and trash were milled and samples of mixed juice and clarified juice were analysed. As expected, the samples of ‘dirty’ cane had higher levels of non-sugars, ash and colour. In another series of trials conducted at a factory, paired tests of dirty and clean cane were milled and the factory process streams were analysed to provide data to determine the economic impact of the trash content. Trash levels were up to 15% of the cane supply. Statistically significant effects included reductions in the sugar content for cane payment, crushing rates and syrup quality and an increase in the production of final molasses.

In a further series of factory trials, harvesting operations were organised into clean and dirty cane periods of up to 6 days each and the effects measured in the factory operations. The main effects were statistically significant increases in the starch, phosphorus and mud solids content of juice from dirty cane. The filter cake % cane increased by up to 37% and the pol loss in cake % pol in cane increased by 16%. The A massecuite quantity dropped marginally while the B massecuite % cane increased by 7% and the final molasses % cane increased by about 20%.

Interestingly, there was no statistically significant difference in the quality of the sugar produced. It should be noted that the factories involved in these trials only produced raw sugar with a typical pol of 98.8 to 99.0.

**Improving the exhaustion of C-sugar magma through on-line measurements of the crystal content (Teddy Libelle, Michael Benne, Bridgitte Grondin-Perez and Jean-Pierre Chabriat)**

On-line measurements and supervision tools become essential when trying to optimise the boiling crystallisation process and limit the impact of the variability of incoming feed streams. Here, on-line measurement of the crystal contents of the sugar magma (massecuite) was based simply on the comparison between the brix of the massecuite (BxMC) and the brix of the mother liquor (BxML). Thus, its implementation was simplified due to the fact that both these types of sensors are often present at industrial sites. The complete mass of crystals in the C-sugar magma, Cm, depends on the crystal contents. From industrial measurements collected at Bois Rouge sugar mill (Réunion), we showed that Cm can increase, decrease or be stable during a boiling crystallisation. When analysing the evolution of Cm, we proposed some methods to optimise the exhaustion of C-sugar magma.

**Impact of trash and high fibre cane on sugar recovery: CERF preliminary results (Laurent Corcodel, Camille Roussel, Eslyne Lemoine, Audrey Thong Chane and Laurent Barau)**

The effect of cane composition on sugar processing has been discussed worldwide. With the development of high-fibre cane, an investigation into the high-fibre effects on sugar processing was considered important. A high-fibre, elite variety was at the end of the CERF breeding program, and the effect of this variety on the sugar milling processes had to be investigated. Firstly, the theoretical impact in sugar plants (sugar losses and milling capacity) was described and secondly, laboratory extractability trials were done. Those experiments were conducted jointly between the CERF breeding department and the sugar processing department.

Different CERF cane varieties were pressed at different pressures (50–250 bar) by a hydraulic press to calculate their extraction rate. Results showed significant differences between
those varieties which could be explained by their pith/fibre ratio. Those indicators will be studied further with the aim to integrate them into the CERF breeding program to select high-fibre clones with a good milling ability.

**Factory trials to determine the effect of green trash on downstream processing (Barbara Muir, Gillian Eggleston and Bryan Barker)**

There is a worldwide shift to green cane from burnt cane harvesting. In South Africa 89% of the cane is still burnt and most of it is hand-cut. Some areas are changing to green cane harvesting due to environmental pressures, increasing labour costs and the current trend to investigate sugarcane trash as biomass for the production of bio-products. This paper reports on the effects of harvesting green billeted and/or whole-stalk sugarcane compared to burnt billeted and/or whole-stalk sugarcane at three South African mills that operate either a tandem mill or diffusers. Sufficient cane of each treatment was harvested and processed at each mill to purge the extraction plant of other cane. Trash tissues, shredded cane, juice and bagasse samples in the front end were collected and analysed. A bulk sample of mixed juice was then transported to the SMRI in Durban and further processed in the SMRI pilot plant to clarified juice, syrup, A massecuites, molasses and raw sugar.

Some of the differences reported include:
- There was a 6–10-fold increase in trash for mechanically harvested burnt and green cane over manually cut burnt cane;
- Cane and juice purities decreased with increasing trash content;
- RS/ash ratios in juice, syrup, massecuite and A molasses increased from burnt billets to green billets in some cases or were similar in other cases; and
- At one factory, there was a slight increase (~10%) in affined sugar colour while the samples from another factory showed a decrease of ~22% in affined sugar colour from burnt to green cane.

**Session 4—Whole crops**

**Whole crop harvesting and processing (Michael Saska and Nicolas Gil Zapata. Presented by Rod Steindl)**

This report presents results from tests done in 2006 in a Louisiana factory with harvesting and processing of the whole crop or ‘complete cane’ (stalk plus trash). The objective was to determine if there was any benefit if the whole crop was harvested green and transported to the factory and then to process the cane with or without the extraneous matter.

For complete cane (CC), the mill harvested green cane with the extractor turned off on the harvester, and the normal green cane (NC) was harvested with the fans on as usual. On December 15, 2006, 367 tonnes of CC were processed in about 4.5 hours at an average of 82 t/h. Sampling of normal cane as a reference could not be done on the same day, because cane delivery problems delayed the start of processing the cane. Sampling of the normal cane (NC) was therefore done on December 20 for a total of 7 hours. The mill operation was interrupted because of boiler problems for about 2 hours, about 2 hours into the test. Based on the information regarding the code and weight of the wagons that arrived at the mill, an estimated 974 tonnes of cane were processed within the period of the test, for an average rate of 139 t/h. The code, weight, and core lab analysis of the cane wagons delivered during each test were averaged and compared with the analysis of prepared cane taken at regular intervals during the test. Because of the time difference between the two tests, the variations reported here between NC and CC may be due in part to other factors than the trash content, e.g. cane and processing conditions, etc. Freezing temperatures at the start of December affected the cane quality, and the four-day delay between the tests probably resulted in further deterioration of the freeze damaged cane and skewed the comparison between complete and normal cane.
No problems were noted when processing whole green cane although the mill operated well below capacity at the time of both tests for other reasons.

An Excel model was used to estimate the economic viability of harvesting, transporting and processing cane with a variable amount of extraneous matter, including the case of whole crop processing, with co-generation with the extra bagasse. Other factors included in the model were the cane composition, sugar content and price, extra cane yield above the 'normal cane' case, the power generation efficiency and sale price, and harvester fuel requirements, with the extractor fans either on or off. The field-to-factory distance and the fuel cost were the decisive factors whether whole-crop harvesting could be profitable. The model also shows the critical effect of pol in bagasse, when milling cane with increased amounts of extraneous matter.

**Experiences gained from whole crop milling (David Moller)**

Whole cane milling (WCM) has been undertaken at two of the factories in the NSW Sugar Milling Co-operative to supply enough biomass to power a co-generation boiler of 30 MW during the 6 months of the non-crushing season. Whole crop milling is the supply of the whole crop (cane billets, leaves and trash) to the factory for processing through the milling tandem.

The initial plan was to transport the whole crop to the factory and then separate the leaf and trash material from the billets prior to milling. However, the prohibitive capital costs were such that this proposal was later rejected. After a short trial, it was decided that all the material would be processed through the milling train. This method of processing was trialled for three weeks during the 2007 crushing season before the factory returned to burnt cane processing.

In the 2008 crushing season, the factory has been processing whole cane for the first eight weeks. Due to an extreme frost in the 2007 growing period, the cane supply during this eight week period has included approximately 30% of frost-affected cane. Assessing the effects of processing the whole crop has been complicated by the inclusion of this frosted cane. Processing whole cane has impacted on every part of the factory. Changes have been made in the feeding, milling and boiler stations, but no changes have been made to the clarification, evaporation, pan or fugal stages until the effects of whole crop processing can be better determined. The observed effects in the factory include:

- Cane feeding – lower bulk density, trash binds together more than billets alone;
- Milling – the fibre rate increased from 40 t/h to 77 t/h and with greater variability;
- New cane payment formula needed;
- NIR system needed to measure fibre in each sample for cane payment;
- Clarification – lower settling rates, additional phosphate not effective in assisting clarification, and higher turbidity of clarified juice;
- Evaporation – poor HTC, faster scaling rate and scale harder to remove;
- Pan boiling – pans operating at only 60–70%, poor circulation (it is possible that frost affected cane contributed to this);
- Sugar quality – higher colour in molasses layer, no real impact on refinery operations; and
- Recovery – pol recovery dropped by 9%, bagasse loss increased by 4%, and molasses loss increased by 5%.

**Composition of non-stalk components of sugarcane and field residues and their effects on composition of mixed juice (Michael Saska and Nicolas Gil Zapata. Presented by Rod Steindl)**

This presentation summarised four independent investigations, carried out at different times and following somewhat differing methodologies. However, the objective was the same: add to the understanding of the composition of the various components of the sugarcane plant, with a focus on
the effects of non-stalk components on the composition of the mixed juice, and to some degree on the potential new industrial uses for field residues after cane harvest, or after separation from stalk billets.

Specifically, the various facets of the work included the 2002 tests in Louisiana of the cane composition during the growth and harvest period, a one-time sampling and determination of composition in 2003 of non-sugars in a major sugar cane variety grown in Colombia, determination of the effects of a commonly used chemical ripener on non-sugar composition of the cane in 2005, and a 4-year (2002 to 2006) test to determine the chemical composition of both the biomass remaining in the field after harvest and the juice extracted from these field residues using laboratory milling equipment.

It is well known that the non-sucrose content of the juice (e.g. ash, reducing sugars, starch, and colorants) extracted from cane trash is higher when expressed on the dry solids basis, than in juice from clean stalk, and, therefore, the purity of the industrial mixed juice is lower than it would be if only clean stalks were milled. However, even though the present data are far from complete and may have been affected by various experimental factors, it is quite apparent that the ratio of reducing sugars over the sum of concentrations of potassium and aconitate (the two major contributors to ash in cane juices) tends to be larger in juices from tops and leaves, than in the juice in the clean billets. This would seem to indicate that cane trash (tops and leaves) in commercial cane supplies may increase the overall RS/Ash ratio and therefore lower the target molasses purity.

**Session 5—Forum review and discussion**

**Processing of green cane through sulphitation process (J.J. Bhagat)**

An overview of the Indian sugar industry was presented that included:

- Importance of the sugar industry to the national economy;
- Value-added products that are generated from the 260 Mt crop of sugarcane;
- Major constraints being faced by the industry; and
- Strategies being adopted to improve productivity including new varieties, sustainable farming systems, extensive upgrades and modernisation of factories and energy conservation, optimisation and power export.

Indian factories produce a bold grain sugar with a very low colour of 50–150 IU typically. The process includes double sulphitation and usually syrup clarification. Trash and other extraneous matter that would cause an increase in the sugar colour are avoided. Mixed juice colour can vary from about 14 000 IU for clean cane up to more than 30 000 IU for cane plus tops and trash.

Some of the disadvantages of the high extraneous matter present in the cane supply when all the biomass is delivered to the factory include:

- Reductions in grinding capacity and sucrose extraction;
- Mill efficiency reduces by 5% and milling capacity by 10–15%;
- Lower quality clear juice (increases in turbidity, residual CaO and PO₄, lower purity, and additional consumption of chemicals);
- Leaf matter introduces an extra high loading of colorants, ash and RS;
- Increases the purity of final molasses; and
- Net benefit to a factory processing 0.5 Mt of clean cane rather than cane with extra trash was estimated at US$1.3m (without a co-generation facility).

**Literature review of burnt/green cane effects on factory processing (Laurent Corcodel)**

A brief summary of some papers to past ISSCT and SASTA conferences was presented. The summary highlighted the difficulties confronting current technologists when trying to reconcile the range of previous investigations because the focus of individual investigations is usually different
and this makes comparisons difficult.

**Poster papers**

_A pilot plant developed in-house for yield and quality increasing of sugar crystallisation_  
(Cédric Damour, Patrick Jeanty, Yannis Hoarau, Michel Benne, Brigitte Grondin-Perez and Jean-Pierre Chabriat)

Crystallisation process is the key stage of sugar production. Increasing demands for yield and quality created a need for optimisation and control of the process. To reduce the influence of variations in cane quality and changes in agro-climatic conditions on the process efficiency, it is essential to perform manufacturing protocols and to develop predictive control strategies. These steps require a series of experiments to reach the best trade-off. In an industrial context, each experiment could damage or stop the production.

Development of a pilot offers the opportunity to run many tests and experiments in the same experimental conditions but at a reduced scale. This poster describes a 1:1000 scale pilot plant for sugar crystallisation developed in-house at the Laboratory of energetic electronic and processes (LE2P) at University of La Reunion. This pilot plant should allow us to test and implant some new advanced control methods that have not been tested _in situ_. Results obtained on C-sugar crystallisation and experimental design of the seeding point study justify the scientific interest in the pilot plant development.

**Site visit to Casernes cane delivery and transfer station**

Cane is delivered to one of the 11 transfer stations by the farmer, usually as single trailer loads towed by a tractor. A core sample is taken from each delivery to the station on arrival. The cane is then transferred to a stockpile if whole stick or transferred directly to a waiting 20 t trailer if billet cane.

The core sample is then sub-sampled into a 5 kg lot and analysed at the site. The subsample is shredded and a 1 kg aliquot is placed into a press at 200 bar for 90 s to provide a juice sample for pol and brix. The fibre is calculated from a regression equation and the weight of the press plug.

**Concluding forum**

The forum discussed the use of the word ‘trash’ and what it represented. This arose because there were variations between research groups on what constituted trash and what was extraneous matter. The consensus within the workshop delegates was:

- **Trash**—the fibrous non-stalk material from the cane plant. This includes all leaf matter and the growing point of the cane stalk.
- **Extraneous matter**—everything left in the field or delivered to the factory that is not processable stalk.

There was general agreement that the best practice for factories to produce good quality sugar was to process clean cane. However, it was also recognised that future economic conditions will dictate that factories will need to maximise the amount of biomass brought into the factory for energy and bio-commodities. Individual conditions will define the most economical and sustainable balance for each organisation.

There was some discussion about future research needs. Papers delivered to the workshop identified a range of problems that factories have faced when processing cane with high levels of trash. The forum concluded that more research should be directed towards:

- An economical trash separation system to handle a cane supply with high levels of trash;
- Identification of suitable chemicals that would assist to alleviate the problems associated with the additional impurities in trash when processing a ‘whole of crop’ cane supply through the factory; and
Consideration of a joint workshop for both agricultural scientists and factory engineers to consider the operating constraints of each sector of the industry and to consider options that benefit the operations of both the field and the factory.

Acknowledgements

The contributions of CERF for hosting the workshop and the organisational efforts of the staff of CERF were greatly appreciated. Other organisations that provided financial support for the workshop included Sucrière de La Réunion, Sucrerie de Bois Rouge, SFSR (Sugar Producers Associations of Reunion Island), RTAS (Association of Sugarcane Technologists of Reunion Island), REI (Réalisations Electroniques & Informatiques), Département de la Réunion, and IRT (Ile de la Réunion Tourisme).

ATELIER FABRICATION ISSCT: LES EFFETS DES CANNES VERTES SUR LA FABRICATION A LA SUCRERIE

Par

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MOTS CLEFS: Cannes Vertes, Paille, Non-Canne, Pertes, Atelier.

Resume

L’ATELIER de la section Fabrication de l’ISSCT, «Effets de la canne verte sur le process», a eu lieu à la Réunion; 51 délégues représentant 10 pays étaient présents. On a discute les effets des cannes vertes avec de la paille en quantités variables, sur les performances et l’opération a l’usine. Ces discussions ont été particulièrement intéressantes pour les sucreries ou la cogénération est une option. On a aussi discute les difficultés associées au traitement des cannes vertes entières et des cannes avec beaucoup de paille. On a pu conclure que la meilleure façon de résoudre les problèmes est l’installation d’un système de nettoyage des cannes vertes, produisant des cannes propres pour la sucrerie. On a aussi conclu qu’il faut continuer à faire des recherches sur les effets des impuretés contenues dans la paille sur la fabrication. Deux sucreries et une station de stockage des cannes ont été visitées.
TALLER DE PROCESO DE LA ISSCT—IMPACTO DE LA CAÑA VERDE SOBRE EL PROCESAMIENTO DEL AZUCAR

Por

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PALABRAS CLAVES: Caña Verde, Material Extraña, Pérdidas, Taller.

Resumen

EN REUNIÓN se realizó un taller sobre proceso organizado por el ISSCT, al cual asistieron 51 delegados de 10 países. El taller fue una ocasión importante y oportuna para revisar y discutir aspectos relacionados con el impacto en las operaciones de la fábrica y su desempeño por el suministro de caña verde que podría incluir altos niveles de materia extraña. Fue particularmente interesante escuchar las experiencias de aquellos ingenios que estaban considerando incrementar su contenido de biomasa con el objetivo de incrementar su capacidad de cogeneración. Muchos de los delegados relataron sus experiencias procesando ‘caña completa’ en la fábrica. Los delegados detallaron los problemas e incrementos en las pérdidas que incurrieron durante el procesamiento de caña con alto contenido de materia extraña. El consenso de los delegados fue que el mejor escenario podría involucrar un sistema de limpieza de la caña en la fábrica de forma tal que solo caña limpia podría ser procesada. El foro recomendó más investigación sobre el efecto del incremento de impurezas en las corrientes de proceso asociada con los altos niveles de materia extraña. Como parte de las actividades del taller, se realizaron visitas a dos ingenios y una estación de entrega de caña.
CLARIFICATION OF CANE JUICE FOR FERMENTATION

By

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KEYWORDS: Juice, Clarification, Fermentation, Turbidity, Insoluble Solids.

Abstract
Fermentation feedstocks in the sugar industry are based on cane juice, B molasses or final molasses. Brazil has been producing ethanol by directing sugarcane juice to fermentation directly or using lower quality juice as a diluent with B molasses to prepare the fermentation broth. One issue that has received only limited interest particularly from outside Brazil is the most appropriate conditions for clarification of the juice going to fermentation. Irrespective of whether the juice supply is the total flow from the milling tandem or a diffuser station or a part of the total flow, removal of the insoluble solids is essential. However, the standard defecation process used by sugar factories around the world to clarify juice can introduce unwanted calcium ions and remove other nutrients such as phosphorus and nitrogen that are considered essential for the fermentation process. An investigation was undertaken by SRI to assess the effects on the constituents of cane juice when subjected to the typical clarification process in an Australian factory and what conditions would be needed to provide a clarified juice suitable for fermentation. Typical juices from one factory were clarified in laboratory trials under a range of pH conditions and the resulting clarified juices analysed. The results indicated that pH had a major effect on the residual concentrations of key constituents in the clarified juice and that the selected clarification conditions are determined by the nominated quality criteria of clarified juice feedstock for fermentation. Further trials were conducted in overseas factories to confirm the results obtained in Australia. It became apparent that the preferred specifications for clarified juice going to fermentation varied from country to country. Each supplier of fermentation technology had criteria applying to clarified juice feedstock that would have a major impact on the standard of clarification required to achieve compliance with the criteria.

Introduction
Although the sugar industry in Brazil has been producing ethanol by directing sugar cane juice to fermentation for many years and has developed significant process technology and experience in this field, the sugar industries in other countries are just embarking on this option. The impetus for the change from crystal sugar to a combination of crystal sugar and ethanol includes the continuing low prices for raw sugar, the rising operating costs and the increasing worldwide demand for biofuels to replace fossil fuels.

One issue that has to be addressed is the most appropriate conditions for clarification of the juice going directly to fermentation. Irrespective of whether the juice supply is the total flow from the milling or diffuser station or a part of the total flow, removal of the insoluble solids is essential.

However, the defecation clarification process used by sugar factories around the world introduces unwanted calcium ions and removes other nutrients such as phosphorus and nitrogen that are considered essential for the yeast.
A review was undertaken by SRI to assess the effects on the constituents of cane juice when subjected to the typical clarification process in an Australian factory.

**Optimum juice conditions**

There is not a lot of information available in the public domain that defines the optimum conditions for clarified juice going to fermentation. However, it is generally agreed that:

- The juice should be free of all insoluble solids;
- The maximum concentration of nutrients should be retained within the juice;
- The turbidity of the clarified juice may not be relevant although one fermentation technology provider has specified a maximum turbidity of about 15 (based on ICUMSA method GS7-21);
- Inversion of sucrose in acidic conditions to fermentable monosaccharides is beneficial; and
- Juice should not be contaminated with bacteria.

As an example, the clarified juice shown in Figure 1 (left) would be unsuitable for a sugar manufacturer but is considered to be suitable for fermentation by some fermentation technology and equipment suppliers.

![Fig. 1—Samples of turbid clarified juice suitable for fermentation (left) and clear clarified juice suitable for sugar production (right).](image)

Fermentec Ltda of Brazil (A. Godoy, 2008; *pers comm.*) provided the data shown in Table 1 on optimum conditions for clarified juice going to fermentation.

| Table 1—Optimum conditions for fermentation juice as specified by Fermentec, |
|---------------------------------|--------------------------|
| Parameter                      | Nominated value          |
| pH of limed juice              | 5.8–6.0                  |
| pH of clarified juice          | 5.0–5.5                  |
| Insoluble solids               | <0.2%                    |
| Calcium                        | As low as possible (<800 mg/kg) |
| Manganese                      | 2.0 mg/kg                |
| Zinc                           | 2.0 mg/kg                |
| Magnesium                      | 200 mg/kg                |
| Phosphorus                     | 50–65 mg/kg              |
| Nitrogen (as NH₃OH)            | 60–70 mg/kg              |
| Turbidity                      | Not important            |
Another fermentation company in South America provided the information shown in Table 2 for the required quality of clarified juice going to fermentation.

**Table 2**—Another specification for fermentation juice in South America.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Nominated value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>70°C</td>
</tr>
<tr>
<td>pH</td>
<td>5.8–6.2</td>
</tr>
<tr>
<td>Reducing sugars</td>
<td>13–14 g/100 mL juice</td>
</tr>
<tr>
<td>Sulphur</td>
<td>0</td>
</tr>
<tr>
<td>Bacterial infection</td>
<td>&lt;1.00 E+06</td>
</tr>
<tr>
<td>Bagacillo</td>
<td>&lt;0.40%</td>
</tr>
<tr>
<td>Insoluble solids</td>
<td>0</td>
</tr>
<tr>
<td>Turbidity</td>
<td>1000–1200 IU</td>
</tr>
<tr>
<td>Dextran</td>
<td>&lt;250 ppm</td>
</tr>
<tr>
<td>Volatile acids</td>
<td>500–1000 ppm</td>
</tr>
</tbody>
</table>

However, there is considerable variation in the target values of quality parameters at factories that are already sending juice directly to fermentation. A survey of some factories in Central and South America (see Table 3) indicates a wide range in pH of the feed juice.

**Table 3**—Range of pH values of clarified juice going to fermentation.

<table>
<thead>
<tr>
<th>Factory</th>
<th>pH of clarified juice</th>
<th>Factory</th>
<th>pH of clarified juice</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>6.8 – 6.9</td>
<td>#6</td>
<td>6.2 – 6.4</td>
</tr>
<tr>
<td>#2</td>
<td>6.0 – 6.2</td>
<td>#7</td>
<td>5.4 – 5.6</td>
</tr>
<tr>
<td>#3</td>
<td>6.0 – 6.2</td>
<td>#8</td>
<td>6.6 – 6.8</td>
</tr>
<tr>
<td>#4</td>
<td>6.0</td>
<td>#9</td>
<td>&lt;6.8</td>
</tr>
<tr>
<td>#5</td>
<td>5.3 – 5.5</td>
<td>#10</td>
<td>6.3</td>
</tr>
</tbody>
</table>

In South America, one new factory with a cane diffuser has eliminated the clarification step. The justification relies on the assumption that the fermentation process and the viability of the yeast can tolerate an insoluble solids level of up to 0.2%. The installed process removes gross solids by filtration before sending the juice to fermentation.

The quality criteria are set to maximise the efficiency of the fermentation process and the viability of the yeast cells but appear not to consider the scaling potential in the evaporator or distillation columns.

**Experimental**

Settling rate tests were conducted on samples of mixed juice that were collected from an Australian factory to examine the effect of different pH levels on the settling rate, turbidity and residual impurities of the resulting clarified juice. The tests involved the following procedure:

- Heat the juice to either 75°C or 90°C;
- Adjust the pH of each one litre sample using lime saccharate to a selected value between 5.8 and 7.6 (the raw juice pH was 5.3);
- Heat the limed juice to boiling;
- Transfer the juice to a settling tube and measure the settling rate and settled mud volume; and
- Collect subsamples for analyses.
Mitsui Superfloc flocculants were tested at 3 mg/kg of juice. These flocculants had molecular weights of $24 \times 10^6$ and hydrolysis levels ranging from 24% to 38% and covered the full range of hydrolysis levels normally used in raw sugar manufacture.

The samples of clarified juice were analysed for turbidity (ICUMSA GS7-21), total phosphorus (ICUMSA GS7-15), calcium by inductively coupled plasma mass spectrometry and total organic nitrogen (Kjeldahl).

**Results**

**Settling tests**

The settling rates were very similar for each test. There appeared to be no effect of pH on the settling rates. Most settling rate results were in the range of 47–52 cm/min. The flocculants used were:

- Sample 1: A2120, A2130
- Sample 2: A2120
- Sample 3: A2120
- Sample 4: A2120, A2115 and A2125

As expected, the mud volume increased as the pH of clarification increased. The results are shown in Figure 2. Juice sample 3 contained less mud solids than the other juice samples. This is reflected in the lower mud volumes shown in Figure 2. Sample 3 also had higher settling rates of 61–64 cm/min because of the reduced effects of hindered settling.

![Figure 2](image)

**Fig. 2**—Results showing the increase in mud volume as more lime saccharate is added to raise the pH of the juice.

Figure 3 shows that the turbidity decreased as the pH of clarification is increased. Under normal clarification conditions when the pH of the feed juice is 7.6 to 7.8, the turbidity would be expected to be less than 10. The results suggest that there was little or no reduction in turbidity between 6.5 and 7.6 pH. Usually there is a much larger reduction in turbidity over this pH range. These results are more a reflection of the properties of the particular juice rather than a typical response.
Fig. 3—Results showing the turbidity reduction as the pH of clarification increases.

Analyses of the clarified juice

Analyses of the clarified juice for calcium, phosphorus and nitrogen showed significant effects of pH as illustrated in Figures 4, 5 and 6.
The reason for the different levels of nitrogen in sample 1 is unknown. The clarified juice samples were not analysed for insoluble solids as the levels were estimated to be significantly below the 0.2% limit suggested by Fermentec.

Visually, the clarified juice samples appeared to contain no insoluble solids. This observation was supported by the relatively low turbidity values of 30 and lower for pH levels of 6.0 and above.

Another series of tests was conducted in an overseas factory using the juice from a bagasse diffuser. Characteristics of this juice include:
• Very low mud solids loadings;
• Low brix;
• Higher levels of impurities; and
• Low phosphorus content.

The implication is that clarifying this juice separately becomes very difficult.

The same test procedure was used but only settling rates, turbidity and mud volume data were collected.

Settling rates were difficult to measure because the mud flocs were relatively light and tended to be affected by any flow currents inside the cylinder. The low number of flocs made it difficult to identify any interface between the juice and the settling mud flocs. The best estimate of settling rate was that it varied between about 15 and 40 cm/min. The settled mud was of lower density than that normally expected from juice flowing from a milling tandem or even from a cane diffuser. The results are shown in Figures 7 and 8.

![Fig. 7—Mud volumes from bagasse diffuser juice for different flocculant types.](image1)

![Fig. 8—Turbidity data from the bagasse diffuser experiments.](image2)
For the samples tested, increasing the pH just between 7.0 and 7.6 made a large difference in the turbidity of the clarified juice. The criteria for clarified juice at this distillery were for a pH of not more than 6.8 and a maximum turbidity of 15. The results suggest that it would be difficult to achieve compliance with the criteria.

Discussion

It is clear from the results obtained that the pH of clarification should be maintained at values below 6.2 if the criteria set by Fermentec are to be maintained. This is primarily to satisfy the minimum phosphorus criterion as compliance with other criteria is maintained at pH levels up to about 6.5.

An advantage of maintaining a pH below 6.5 is that alkaline degradation of reducing sugars to organic acids is avoided. According to Fernando Perez (pers comm., 2008) concentrations of organic acids above about 5000 ppm are detrimental to the fermentation process.

Previous experiments by SRI determined that the residual calcium levels in clarified juice started to rise once the pH was increased above about 6.5. Those experiments also determined that other inorganic ions such as manganese, magnesium and zinc were not affected by the normal defecation process used for the clarification of cane juice. The present data support that conclusion with respect to the residual calcium level. The clarified juice samples collected during the investigation reported here were not analysed for magnesium, manganese or zinc. At pH levels below 6.5, all the calcium added as calcium saccharate reacted with phosphorus in the juice to form calcium phosphate precipitate. There was no increase in residual calcium above the base level provided the pH of clarification remained below about 6.5.

Precipitation of calcium phosphate by the addition of lime to react with the phosphorus that occurs naturally in the juice is an essential pre-requisite to the standard clarification process. The calcium phosphate forms a bridge between the anionic flocculant and the insoluble solids. The large flocs formed by this linkage ensure high settling rates and provide an effective mechanism for the removal of other solids from the juice. Without the calcium phosphate precipitate, more expensive processing options would be required to remove the insoluble solids from the juice.

The option of avoiding a clarification step for diffuser juice takes advantage of the low initial solids level in the juice, typically 0.1 to 0.25%. Potentially most of the remaining solids could be removed by self cleaning rotary filters with small aperture (<100 µm) screens. Heating and evaporation steps are still required and higher scaling rates in the evaporator and distillation columns are expected.

When these results are applied to a decision on the type of clarifier and the residence time built into that clarifier, the obvious conclusion is that the installation of a clarifier with a long residence time offers no advantage. This conclusion is based on the following:

- The settling rates are high, even at the low pH levels.
- There are no chemical reactions (except sucrose inversion) that occur in the clarifier that could benefit the performance of the clarifier or the subsequent fermentation process.

The SRI NG clarifier with its short residence time can be applied to the clarification of juice for fermentation. The latest design has been developed through the application of computational fluid dynamics to examine the trajectories of floc particles under a range of operating scenarios to provide optimum conditions that will ensure the effective separation of the insoluble solids from the juice. Other clarifier designs can also be used for this application provided they are operated efficiently.

The experimental data are applicable to the juices being processed at the various factories during the period when the samples were collected. The results may not be fully applicable to other
factories although the trends should be similar irrespective of the source of the cane supply. The settling rates of other juices will vary depending on a number of properties including mud solids content, phosphorus concentration and the flocculant being added.

It is most likely that some juices will have lower settling rates, particularly when operating at the low pH levels or when the mud solids content is higher. Low settling rates can also result when the juice pre-treatment conditions deviate from set points. In these cases the risk of carryover of small mud particles will increase.

The settling rate of the mud is the most important parameter to be used when selecting the appropriate size of clarifier for a nominated juice flow rate. Realistic settling rate data must be used when selecting the diameter of the clarifier so that clarification standards are maintained during periods when low settling rates exist. Thus it is important for the design team to work with the client to determine the most appropriate size of clarifier to suit their particular application.

Maintaining a balance between the charge density on the mud particles and the flocculant is an important consideration irrespective of the destination for the clarified juice. When operating at low pH levels, it becomes more difficult to achieve a consistently high clarification standard because the charge density on the mud particles can be much lower.

Conclusions

Experiments conducted by SRI have shown that the optimum pH for the clarification of juice going to fermentation is below 6.2 if the criteria nominated by fermentation technology providers are to be maintained.

The results indicate that the short residence time clarifiers such as the SRI NG clarifier are also suitable for this application irrespective of the specification applied to the clarified juice. Where clarified juice of low turbidity is required, it is important to get the chemistry of the clarification process correct. If tight control of the chemical conditions is not maintained, it will be difficult to comply with the nominated standards.

Depending on the specification of the clarified juice, treatment of diffuser juice may not require a clarification step. This presents an opportunity to investigate other processes that may satisfy the requirements for fermentation feedstock.
monde entier afin de clarifier les jus peut introduire des ions calcium indésirables et supprimer les autres éléments nutritifs tels que le phosphore et azote qui sont considérés comme essentiels pour le processus de fermentation. Une étude a été entreprise par le SRI pour évaluer les effets sur les constituants du jus de canne lorsqu'il est soumis au processus de clarification typique dans une usine australienne; on a aussi étudié les conditions nécessaires pour fournir un jus clarifié adapté à la fermentation. Des jus typiques provenant d'une usine ont été clarifiés dans le laboratoire sous un éventail de conditions de pH et le jus clarifié résultant analysé. Les résultats ont révélé que le pH avait un effet majeur sur les concentrations des constituants principaux résiduels dans le jus clarifié et que les conditions de clarification sélectionnées sont déterminées par les critères de qualité nécessaires pour les jus destinés à la fermentation. Des essais complémentaires ont été effectués dans des usines à l'étranger pour confirmer les résultats obtenus en Australie. On a trouvé que les spécifications préférées pour les jus clarifiés destinés à la fermentation varient d'un pays à l'autre. Chaque fournisseur de technologie de fermentation se sert de critères pour le jus clarifié qui ont un impact majeur sur le processus de clarification.

CLARIFICACION DE JUGO DE CAÑA PARA FERMENTACION

Por

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PALABRAS CLAVES: Jugo, Clarificación, Fermentación, Turbiedad, Sólidos Insolubles.

Resumen

La materia prima para la fermentación en la industria azucarera está basada en jugo de caña, mieles B o miel final. Brasil ha estado produciendo etanol fermentando jugo caña o usando jugo de calidad para diluir la miel B y preparar el caldo de fermentación. Un tema que ha recibido poca atención particularmente en países diferentes a Brasil ha sido el de encontrar las condiciones más apropiadas para la clarificación del jugo que posteriormente se va a fermentar. Independiente si el flujo total del jugo es suministrado por un tándem de molinos ó por una estación de difusión, es esencial la remoción de los sólidos insolubles. Sin embargo, el proceso estándar de defecación usado por las industrias azucareras alrededor del mundo para clarificar el jugo puede introducir iones de calcio indeseados y remover otros nutrientes tales como fósforo y nitrógeno que son considerados esenciales en el proceso de fermentación. El SRI realizó una investigación para valorar los efectos en la composición del jugo de caña cuando es sometido al típico proceso de clarificación en un ingenio australiano y las condiciones que podrían ser requeridas para suministrar un jugo apto para la fermentación. Los jugos de caña de un ingenio fueron clarificados en ensayos de laboratorio bajo un rango de pH. Los jugos clarificados fueron analizados. Los resultados indicaron que el pH tiene un efecto importante en las concentraciones residuales de los constituyentes claves del jugo clarificado y que las condiciones bajo las cuales se realice la clarificación debe ser seleccionadas de acuerdo con los criterios de calidad requeridos para fermentar el jugo clarificado. Se pudo establecer que aparentemente las condiciones deseadas para un jugo clarificado que se va a fermentar varían de un país a otro. Las empresas que suministran las tecnologías de fermentación han establecido criterios para el jugo clarificado que podrían tener un mayor impacto en el nivel de clarificación requerido para lograr el cumplimiento de estos criterios.
LOW MOISTURE MUD FROM SOLID BOWL DECANTERS

By

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KEYWORDS: Clarifier Mud, Solids, Moisture, Filter, Centrifuge.

Abstract

The high moisture content of mill mud (typically 75–80% for Australian factories) results in high transportation costs for the redistribution of mud onto cane farms. The high transportation cost relative to the nutrient value of the mill mud results in many milling companies subsidising the cost of this recycle to ensure a wide distribution across the cane supply area. An average mill would generate about 100 000 t of mud (at 75% moisture) in a crushing season. The development of mud processing facilities that will produce a low moisture mud that can be effectively incorporated into cane land with existing or modified spreading equipment will improve the cost efficiency of mud redistribution to farms; provide an economical fertiliser alternative to more farms in the supply area; and reduce the potential for adverse environmental impacts from farms. A research investigation assessing solid bowl decanter centrifuges to produce low moisture mud with low residual pol was undertaken and the results compared to the performance of existing rotary vacuum filters in factory trials. The decanters were operated on filter mud feed in parallel with the rotary vacuum filters to allow comparisons of performance. Samples of feed, mud product and filtrate were analysed to provide performance indicators. The decanter centrifuge could produce mud cakes with very low moistures and residual pol levels. Spreading trials in cane fields indicated that the dry cake could be spread easily by standard mud trucks and by trucks designed specifically to spread fertiliser.

Introduction

Mud from the mud filters contains nutrients making it of value as a soil conditioner and substitute for commercial fertilisers but it also contains a large proportion of moisture (typically 75–80% in Australian factories).

Following an extensive assessment of the nutrient value of mill mud versus the application of commercial fertilisers, Qureshi et al. (2000) concluded that, for farms within 25 km of mills in the Central Queensland region, it was economical for farmers to apply mill mud (at 75% moisture) at rates up to 150 t/ha for substitution of commercial fertilisers.

The development of mud processing facilities that would produce a low moisture mud that could be spread onto cane fields with existing or modified spreading equipment will:

- Improve the cost efficiency of mud redistribution to farms broadly across the mill area;
- Provide an economical fertiliser alternative to more farms in the supply area; and
- Reduce the risk of environmental impact from farms.

It was proposed to investigate whether a solid bowl decanter could reduce the moisture of the final mud product without any extra loss of pol in the cake and without any increase in the level of mud solids recycled back to process with the filtrate.

Previous investigations
Hale et al. (1974) conducted factory trials on a decanter supplied by Sharples-Stokes. They concluded that one of the biggest problems was maintaining a high level of mud solids retention in the cake. They investigated feed conditioning options including the addition of lime to raise the pH, dilution of the feed and addition of flocculant and bagacillo to improve the retention. The most significant improvement was achieved with a high pH (~10) feed.

Stewart et al. (1974) conducted trials on a MercoBowl solid bowl centrifuge at another factory. This machine had facilities to add wash water at several positions along the inclined beach section.

A maximum pol recovery of 91% was achieved when dilution water was added to the feed. A higher pol recovery was possible when wash water was applied to the cake on the beach section but at the expense of reduced retention.

The amount of fibre in the mud affected the mud solids retention. Increasing the fibre ratio from about 0.27 to 0.4 improved the mud solids retention from 45–50% up to about 65%. The addition of flocculant improved the mud solids retention but did not affect pol recovery.

Stewart et al. (1975) showed that as flow rate through a solid bowl centrifuge increased, mud solids retention decreased. The pol loss was two to three times higher than that achieved by a rotary drum vacuum filter (RVF).

Stewart et al. (1976) investigated the effect of the finer bagacillo on the performance of the centrifuge. The performance of the MercoBowl was found to have improved significantly during the 1975 season compared with previous performances.

This improvement was shown to be a direct result of the finer bagacillo supply available from the new heavy duty shredder. Mud solids retention improved to above 90% even at high feed rates and the pol loss was reduced by about one third.

Danish Sugar & Sweetener Engineering (DSSE, 2004) was developing a decanter specifically for use on clarifier mud. Results provided by DSSE indicated the following:

- Cane quality and concentration of suspended solids had a significant effect on the capacity and pol loss;
- The use of a suitable flocculant was essential;
- The centrate was a clear lemon yellow juice;
- No bagacillo was necessary;
- The cake moisture averaged 58% over all tests; and
- The average cake pol was 3.2%.

**Methodology**

Factory trials were conducted to assess the potential of a solid bowl decanter centrifuge (SBC) to produce low moisture mud.

Two SBCs were tested. The first series of trials was conducted on a model P3400 SBC supplied by Alfa Laval.

The initial results of the P3400 indicated higher than acceptable pol losses and poor retention of the mud solids in the SBC so a second series of trials was conducted in the following year on a skid-mounted G2 40 decanter centrifuge unit also supplied by Alfa Laval.

The arrangement of the pilot plants for the factory trials is illustrated in Figure 1. The feed for the SBC was bled from the mud feed to the existing RVFs.

Hot flushing water was supplied at the top of the supply pipe. A magnetic flowmeter and resistance thermometer measured the flow rate and temperature of the mud feed to the SBC.
The centrate from the SBC was discharged to a small tank and then pumped to the secondary juice tank. The mud product was removed by a conveyor, stockpiled and finally removed by a front end loader at appropriate intervals.

Trials were conducted on both SBCs over a range of processing conditions. Some trials were conducted by collecting filter cake from the RVF, adding water to reconstitute the mud and then pumping the mud through the SBC. The mud was reconstituted in the mixer bowl of a concrete truck. Just enough water was added and mixed with the cake from the RVF to make the reconstituted mud fluid enough to flow to the SBC. The concept was to simulate conditions where a factory with limited filter area would process thicker cakes than optimum through the existing filter station and then reprocess the reconstituted mud through a SBC as a two-stage process to recover more sucrose and to produce a drier mud product.

The reconstituted mud was continuously discharged from the concrete truck and pumped to the centrifuge (as shown in Figure 1). Each batch from the concrete truck contained around 2.5 t of reconstituted mud and was sufficient to run the centrifuge at maximum rate (around 10–11 t/h) for about 15 minutes.

Stockpiled mud product from the centrifuge was loaded into a fertiliser truck and spread onto a nearby cane field to determine if there were issues with the transportability and spreadability of the low moisture mud.

Samples of feed and mud product from the RVFs and SBCs were collected during the trials and were analysed for pol, moisture, fibre and mud solids. Samples of centrate from the SBCs were also collected and analysed for pol, brix, purity and insoluble solids. During each trial, the bulk density and slump of the mud product was also tested. The slump was measured using concrete slump testing equipment (Anon., 1978; Anon., 1998). The slump of the mud product was measured to provide indications of the angle of repose and how easily the mud would flow from a mud truck.

**Pilot equipment**

The model P3400 decanter centrifuge supplied by Alfa Laval shown in Figure 2 had a rated capacity of 11 t/h of mud feed at 10% mud solids. The mud feed was introduced through a rotating
scroll into a rotating bowl. The scroll rotated at a small differential speed to the bowl. The bowl was driven by a 30 kW motor at around 3200 r/min and the scroll was driven by a 4 kW back drive motor connected by a vee-belt to the gearbox. The unit had no facilities for internal washing of the mud product.

Fig. 2—The P3400 pilot centrifuge used during the factory trials.

The skid-mounted G2 40 decanter centrifuge unit supplied by Alfa Laval for the second series of trials is shown in Figure 3. The skid was a turnkey system and just required connection of three phase power and connections for water, mud feed and centrate and a conveyor to remove the mud cake.

Fig. 3—The G2 40 decanter centrifuge used during the factory trials.
The G2 40 decanter had more instrumentation than the P3400 unit including an automatic polymer dosing rig, mud feed pump and magnetic flowmeters. It also had an internal baffle arrangement which was designed to press the dried mud product against the stator prior to discharge to achieve a further reduction in the final moisture content.

During the trials, the feed rate was adjusted between 3.7 and 8.0 t/h; however, for the majority of the trials where the effect of flow rate was not the object of investigation, the mud feed pump was set to deliver the maximum feed rate of 7–8 t/h. This was the capacity limit of the mud feed pump rather than the capacity limit of the centrifuge. The speed differential between the bowl and the scroll ranged between 8 and 27 r/min.

The most significant facility of the G2 40 was the torque monitoring instrumentation. The torque provides an indication of the degree of separation between the solids and the liquid within a centrifuge; the higher the torque, the better the separation.

By altering variables that increase the torque (usually speed differential between the bowl and the scroll), the operator is able to improve separation of the solid component from the liquid component for any given set of operating conditions.

The flocculant pump fed into a manifold which allowed the flocculant to be added into the feed at a number of locations prior to the centrifuge.

**Factory trials**

**Solid bowl decanter centrifuge trials**

**P3400 centrifuge**

A total of 33 trial conditions investigating combinations of speed differential (5 to 20 r/min), feed rate (2.6 to 8.7 t/h) and flocculant dose (Superfloc A2115 at 0 to 1320 ppm on mud solids in feed) were tested.

**G2 40 centrifuge**

During the trials on the G2 40 centrifuge, there was an emphasis on maximising the mud solids retention. The variables adjusted included the flocculant addition rate (600 to 2500 ppm on mud solids in the feed), the fibre ratio of the mud feed (0.25 to 0.6), the feed rate (3.7 to 8.0 t/h), and the differential speed between the bowl and the scroll (8 to 27 r/min). The centrifuge was used to process mud from the mud mixer and reconstituted mud from the RVF.

Sucrafloc 2320 flocculant was added to the mud feed at 89 to 336 litres per hour to achieve 600 to 2500 ppm on mud solids. It had been found that Sucrafloc 2320 was better suited for flocculating the mud than the Superfloc 2115 used for the P3400 trials.

**Results and discussion**

**Rotary vacuum filter**

Table 1 provides a summary of the results collected during the RVF trials. When dilution water was added to the clarifier underflow and wash water was turned off, a visible reduction in the moisture content of the cake was achieved. The final moisture of the cake reduced from 77–79% to 69–72%.

It appears that there is a distinct limit to the amount of water that can be removed. As the cake dries, the cake starts to crack and air passes through the cake and into the filtrate pipes. Once air starts passing through the cake, the vacuum reduces since the drum is no longer sealed.

In one test, the vacuum dropped to –15 kPa g compared to the typical vacuum of –70 kPa g. During this test, the cake thickness also increased from 6–8 mm under normal operation to 11–13 mm. Composite cake samples collected during the trials indicated that the pol % mud solids increased by an average 6.5 times when the wash water was off.
### Table 1—Summary data from the RVF trials.

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Wash water on</th>
<th>Wash water off</th>
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<tbody>
<tr>
<td>Feed rate (t/h)</td>
<td>57.8</td>
<td>78.0</td>
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<tr>
<td>Cake rate (t/h)</td>
<td>24.1</td>
<td>20.0</td>
</tr>
<tr>
<td>Filtrate rate (t/h)</td>
<td>74.3</td>
<td>58.0</td>
</tr>
<tr>
<td>Wash water (t/h)</td>
<td>40.7</td>
<td>0</td>
</tr>
<tr>
<td>Wash water%cake</td>
<td>169</td>
<td>0</td>
</tr>
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</table>

<table>
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<tr>
<th>Mud feed analyses</th>
<th>Pol (%)</th>
<th>Moisture (%)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>6.71</td>
<td>86.1</td>
</tr>
<tr>
<td>Fibre (%)</td>
<td>1.45</td>
<td>1.54</td>
</tr>
<tr>
<td>Mud Solids (%)</td>
<td>4.52</td>
<td>4.49</td>
</tr>
<tr>
<td>Fibre ratio</td>
<td>0.32</td>
<td>0.34</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cake analyses</th>
<th>Pol (%)</th>
<th>Moisture (%)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>0.67</td>
<td>78.3</td>
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<tr>
<td>Fibre (%)</td>
<td>7.32</td>
<td>7.15</td>
</tr>
<tr>
<td>Mud Solids (%)</td>
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<td>15.85</td>
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<tr>
<td>Fibre ratio</td>
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<tr>
<td>Pol%mud solids</td>
<td>4.9</td>
<td>32.0</td>
</tr>
<tr>
<td>Cake density (kg/m³)</td>
<td>665</td>
<td></td>
</tr>
</tbody>
</table>

**Solid bowl decanter centrifuge trials**

#### P3400 centrifuge trials

The trials with the P3400 centrifuge focussed on determining the minimum moisture content of the mud product achievable with a decanter centrifuge. Initial results indicated that 51.8% moisture was achieved but with a mud pol of 8.2. These results were obtained without attempting to minimise pol loss. The mud product was promising since it was highly spreadable but further work to improve the properties of the mud (pol and bulk density) was required.

The centrifuge also had poor retention of mud solids (around 50%). This meant that the fibre ratio of the mud product was high (around 0.7) and the bulk density was low. Increasing the mud solids retention and maintaining a high recovery of sugar is necessary to ensure the economic viability of the process.

Feed rate and weir depth settings in the decanter were found to be the most important variables affecting final moisture content. The driest mud product had a high proportion of fibre and was generally of low bulk density (median of 327 kg/m³). The trials showed that the centrifuge could produce mud product between 47% and 61% moisture. Selected results of the trials with the P3400 centrifuge are shown in Table 2.

A summary of the results of the trials on the P3400 centrifuge follows:

- By decreasing the differential speed between the bowl and the scroll, a drier cake can be achieved but the solids loading of the centrate is increased. It was found that adjusting the differential speed had only a minor impact on the performance of the centrifuge.
- It was found that adjusting the weir depth had a profound effect on the moisture content of the cake and the mud solids loading in the centrate. By decreasing the weir depth, a drier cake could be produced but the resulting centrate had a higher solids loading as a consequence.
- The feed rate appeared to have a moderate effect on the performance of the centrifuge. The maximum feed rate was limited by the ability of the filtrate pump to
remove the centrate. The feed rate was measured by a magnetic flowmeter while the mud product rate was determined by weighing the cake falling from the conveyor with a large bucket and a stopwatch.

- The mud solids retention of the mud product was particularly poor; ranging between 47 and 90%. The average retention was 60.1%. The pol% mud solids was too high (28.6–42.5%) due to the absence of any facility to wash the cake.

The mud product generated from the centrifuge appeared to be attractive as garden compost. During the trials, stockpiles of mud disappeared, taken by various mill staff as compost. There seems to be an opportunity to value-add to the mud produced by the centrifuge as a feedstock for granulation or pelletising.

Many mills are battling with insufficient filter area to process adequately the mud flow. One option is to implement a two-stage process where the existing rotary drum filters comprise the first stage. The second stage would consist of a reconstitution phase where the cake is mixed with water and then fed to a decanter centrifuge. It was expected that the final mud pol could be significantly reduced.

Results from the mud reconstitution trials are shown in Table 2. The tests were successful in reducing the pol % mud solids to well below 1.0%. During the reconstitution trials, there was an increase in the moisture content of the mud product to 58–65%. This increase in moisture compared to trials with fresh mud from the mud mixer was in spite of the low weir setting which would normally be expected to provide the driest cake.

### Table 2—Summary of trials using the P3400 decanter centrifuge.

<table>
<thead>
<tr>
<th>Feed type</th>
<th>Fresh mud from mud mixer</th>
<th>Reconstituted mud</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mud feed analyses</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feed rate (t/h)</td>
<td>6.70</td>
<td>5.65</td>
</tr>
<tr>
<td>Cake rate (t/h)</td>
<td>0.70</td>
<td>0.55</td>
</tr>
<tr>
<td>Pol (%)</td>
<td>11.63</td>
<td>11.74</td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>11.63</td>
<td>11.74</td>
</tr>
<tr>
<td>Fibre (%)</td>
<td>1.44</td>
<td>1.64</td>
</tr>
<tr>
<td>Mud Solids (%)</td>
<td>5.37</td>
<td>5.83</td>
</tr>
<tr>
<td>Fibre ratio</td>
<td>0.27</td>
<td>0.28</td>
</tr>
<tr>
<td>Flocculant rate (ppm MS)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Cake analyses</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pol (%)</td>
<td>7.98</td>
<td>7.21</td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>52.91</td>
<td>48.22</td>
</tr>
<tr>
<td>Fibre (%)</td>
<td>16.44</td>
<td>19.01</td>
</tr>
<tr>
<td>Mud Solids (%)</td>
<td>20.68</td>
<td>23.77</td>
</tr>
<tr>
<td>Fibre ratio</td>
<td>0.79</td>
<td>0.80</td>
</tr>
<tr>
<td>Pol% mud solids</td>
<td>38.6</td>
<td>30.3</td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td>326.0</td>
<td>327.0</td>
</tr>
<tr>
<td><strong>Centrate analyses</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pol (%)</td>
<td>13.00</td>
<td>13.15</td>
</tr>
<tr>
<td>Bx</td>
<td>14.79</td>
<td>14.90</td>
</tr>
<tr>
<td>Pty (%)</td>
<td>87.9</td>
<td>88.2</td>
</tr>
<tr>
<td>Insoluble Solids (%)</td>
<td>2.78</td>
<td>2.58</td>
</tr>
<tr>
<td>Retention (%)</td>
<td>53.4</td>
<td>60.2</td>
</tr>
<tr>
<td>Pol recovery</td>
<td>0.93</td>
<td>0.94</td>
</tr>
</tbody>
</table>

### G2 40 centrifuge trials

The P3400 trials gave good results for final product moisture but poor results for mud solids retention and pol loss. The high pol loss was overcome by reconstituting the mud (albeit at the expense of product moisture).
Data from the trials by Stewart et al. (1974) indicated that greater than 97% mud solids retention was possible under certain conditions.

Averaged results of the trials with the G2 40 centrifuge are shown in Table 3 including results from the mud reconstitution trials. The main conclusions of the results for the G2 40 centrifuge are:

- When fed with mud from the mud mixer, the centrifuge was able to achieve 53–58% moisture cake;
- The cake moisture was low in spite of the high weir setting;
- Mud solids retention was close to 100%;
- The high mud solids retention is reflected in the low solids level in the centrate;
- The fibre ratio of the cake product reduced from 0.77 for the P3400 to 0.49 for the G2 40 because of the much improved retention of mud solids;
- The cake moisture and retention were independent of the feed rate;
- The pol loss remained at an unacceptably high level;
- Flocculant usage to achieve these results was high; and
- All centrates would be suitable for forward processing.

Table 3—Summary of trials using the G2 40 decanter centrifuge.

<table>
<thead>
<tr>
<th>Feed type</th>
<th>Fresh mud from mud mixer</th>
<th>Reconstituted mud</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mud feed rate (t/h)</td>
<td>7.89</td>
<td>12.96</td>
</tr>
<tr>
<td>Cake rate (t/h)</td>
<td>1.36</td>
<td>2.27</td>
</tr>
<tr>
<td>Pol (%)</td>
<td>12.54</td>
<td>11.79</td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>79.2</td>
<td>79.9</td>
</tr>
<tr>
<td>Fibre (%)</td>
<td>1.68</td>
<td>1.49</td>
</tr>
<tr>
<td>Mud Solids (%)</td>
<td>5.01</td>
<td>5.30</td>
</tr>
<tr>
<td>Fibre ratio</td>
<td>0.34</td>
<td>0.28</td>
</tr>
<tr>
<td>Flocculant (ppm mud solids)</td>
<td>1228</td>
<td>648</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Feed type</th>
<th>Fresh mud from mud mixer</th>
<th>Reconstituted mud</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pol (%)</td>
<td>8.71</td>
<td>8.24</td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>55.70</td>
<td>54.35</td>
</tr>
<tr>
<td>Fibre (%)</td>
<td>10.60</td>
<td>11.50</td>
</tr>
<tr>
<td>Mud Solids (%)</td>
<td>22.75</td>
<td>23.90</td>
</tr>
<tr>
<td>Fibre ratio</td>
<td>0.47</td>
<td>0.48</td>
</tr>
<tr>
<td>Pol%mud solids</td>
<td>38.3</td>
<td>34.5</td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td>517.0</td>
<td>583.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Feed type</th>
<th>Fresh mud from mud mixer</th>
<th>Reconstituted mud</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pol (%)</td>
<td>13.50</td>
<td>12.30</td>
</tr>
<tr>
<td>Bx</td>
<td>15.10</td>
<td>13.80</td>
</tr>
<tr>
<td>Pty (%)</td>
<td>89.7</td>
<td>89.2</td>
</tr>
<tr>
<td>insoluble Solids (%)</td>
<td>0.005</td>
<td>0.14</td>
</tr>
<tr>
<td>Retention (%)</td>
<td>99.95</td>
<td>98.35</td>
</tr>
<tr>
<td>Pol recovery</td>
<td>0.93</td>
<td>0.93</td>
</tr>
</tbody>
</table>

A large amount of flocculant was used during the G2 40 trials even though Stewart et al. (1976) found that around 400 ppm gave adequate mud solids retention.

Increasing the fibre ratio, while improving the mud solids retention, had a detrimental effect on the final cake moisture as shown in Figure 4.

The following equation was developed to predict the final moisture content of the mud product.

\[
\text{Final cake moisture} \% = 100 \times (0.455 \times \text{FR} + 0.417)
\]

where FR = fibre ratio of the mud feed to the centrifuge (dimensionless).
Observations from the trials on reconstituted mud feed to the G2 40 include:

- Reconstituting the mud reduced the final pol loss significantly;
- The moisture of the cake was higher than the moisture achieved when fresh feed from the mud mixer was used; and
- Although there was a decline in the retention, the retention level was still acceptable.

**Field distribution trials**

The mud cake from the centrifuges appeared to have excellent spreadability characteristics. It was arranged to load a truck normally used to distribute gypsum and fertiliser with typical cake product from the centrifuge (i.e. 52–58% moisture) and spread it onto a nearby cane field (see Figure 5).
One of the concerns of the spreading trials was that the mud would be blown away because the mud resembled a relatively fine powder. When the trial was performed, it was particularly windy; however, a good uniform layer of mud product remained on the ground.

The truck operator was satisfied with the spreading performance of the cake and considered this distribution method to be viable.

There was interest in how a standard mud truck would handle the dry cake from the SBCs. Truck operators would normally ensure that the cake was wet to prevent any difficulties during spreading operations.

Approximately 8–10 tonnes of cake generated by the centrifuge were loaded into a 15 tonne mud truck. The truck was then driven 10 km to a local farm where it was unloaded. It was thought compaction of the mud product on the journey may hinder its subsequent ability to be discharged uniformly from the truck.

However, once the mud began to move, the mud flowed smoothly and evenly from the truck until it was empty. The resulting mud layer was around 50 to 70 mm thick on the ground.

The lower bulk density of the mud product (400 to 600 kg/m$^3$) from a centrifuge is an important consideration for the logistics of transporting the mud back to the cane field. Assuming 12 tonnes of mud is presently removed with each truck, and the bulk density is 665 kg/m$^3$, 18 m$^3$ of mud is transported with each truck. This represents about 1.63 tonnes of mud solids (assuming 13.6 mud solids%cake).

It was found that 18 m$^3$ of centrifuged mud product (assuming the mud has been reconstituted) contains only 1.51 tonnes of mud solids. However, the weight of 18 m$^3$ of centrifuged mud is only 8.15 tonnes.

Consequently, the volume of the truck filled with mud would need to be increased to remove the same quantity of mud solids with each truckload. A truck with an increased capacity to carry 12 tonnes of the drier cake would remove 2.22 tonnes of dry mud solids, about 35% more mud solids in each load.

**Conclusions**

Tests on the RVFs indicated that the moisture of the cake could only be reduced to 69–72%. This could only be achieved when no wash water was applied to the cake. As the cake dried, excessive air entered the filtrate pipes through cracks in the cake and caused significant loss in vacuum. There was also a 7 to 10 fold increase in the pol loss when the wash water was turned off.

The results from the SBC trials using typical filter feed can be summarised as follows:

- The final cake product was a powder of relatively low density;
- Final cake moistures approaching 50% are possible;
- The pol loss was high because there were no washing facilities in either of the SBC machines tested; and
- The use of flocculant and bagacillo was essential to maintain a high retention of the mud solids.

The results from the SBC trials using reconstituted mud are summarised as follows:

- A feed with a minimum of 85% water is required to produce a feed with sufficient fluidity to feed to the decanter centrifuge;
- A very low pol loss is possible;
- The final cake moisture was slightly higher, due in part to the higher bagacillo content and the need to use a high dosage of flocculant;
- High retention levels are possible only if the feed is conditioned with a suitable flocculant and sufficient bagacillo.
There appear to be no disadvantages associated with the distribution of dry mud product onto cane fields using conventional mud trucks or trucks that are designed to broadcast fertilisers.

Acknowledgments

Sincere thanks are due to the factory staff where the trials were conducted and to Alfa Laval for the loan of the pilot units for the trials. Funding for this project was provided by a syndicate of Australian mills and, via the Sugar Research and Development Corporation (SRDC), from the sugar industry and the Australian Government.

REFERENCES


DÉCANTEURS A BOL SOLIDE POUR PRODUIRE DES BOUES A FAIBLE TENUE EN EAU

Par

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MOTS CLEFS: Décanteur Boue, Solides, Humidité, Filtrer, Centrifuger.

Résumé

L’HUMIDITÉ élevée des boues de moulins (généralement 75 à 80% pour les usines australiens) cause de forts frais de transport pour la redistribution de la boue sur les champs de canne à sucre. Les frais de transport élevés par rapport à la valeur nutritive des boues recènt la subvention des frais de ce recyclage par la sucrerie. Un moulin moyen génère environ 100 000 tonnes de boue (à 75% d'humidité) en une saison. Le développement d’installations qui produiraient une boue à faible
teneur en eau et facilement intégrée au sol serait favorable à la rentabilité; cela donnerait aussi une alternative économique aux engrais et réduirait le risque d'effets environnementaux négatifs. Une étude pour évaluer les centrifugeuses à bol solide pour réduire l'humidité et le pol de la boue a été entreprise et les résultats comparés a ceux de filtres rotatifs à vide existants dans les usines. Les centrifugeuses à bol solide ont traité la boue en parallèle avec les filtres rotatifs sous vide pour permettre des comparaisons de performances. Des échantillons de boue, de gâteau et de filtrat ont été analysés pour fournir des indicateurs de performance. La centrifugeuse à bol solide a produit des gâteaux avec des humidités et des pol très faibles. La dispersion des gâteaux dans les champs de canne à sucre a indiqué que le gâteau sec se propage facilement avec les camions standard et par des camions conçus pour répandre des engrais.

BAJA BARRO DE HUMEDAD DE SÓLIDOS
CUENCO DECANTADORES

Por
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PALABRAS CLAVES: Lodos del Clarificador,
Sólidos, Humedad, Filtros, Centrífuga.

Resumen
El alto contenido de humedad de la cachaza (típicamente entre 75-80% en ingenios Australianos) da como resultado un alto costo de transporte durante su redistribución en las fincas cañeras. El alto costo de transporte relacionado con el valor nutritivo de la cachaza hace que muchas compañías azucareras subsidien este costo para asegurar la amplia distribución de la cachaza a lo ancho del área sembrada en caña. Un ingenio en promedio puede llegar a producir 100 000 t de cachaza con 75% de humedad durante la zafra. El desarrollo de un equipo que producirá cachaza de menor humedad que pueda ser incorporada adecuadamente a las tierras cañeras con los equipos existentes o con modificaciones en el equipo de dispersión incrementará la eficiencia en el costo de redistribución de la cachaza en las fincas cañeras y ofrecerá un fertilizante económicamente atractivo para la mayoría de las fincas en el área de suministro de caña, y reducirá el potencial impacto ambiental adverso desde las fincas. Se realizó una investigación para evaluar un decantador centrífugo sólido de canasta para producir cachaza con baja humedad y bajo pol residual los resultados fueron comparados con el desempeño obtenido en el existente filtro rotatorio al vacío en experimentos llevados a cabo en las fábricas. Los decantadores fueron operados sobre el filtro de alimentación de lodos en paralelo con el filtro rotatorio al vacío para permitir comparaciones sobre su desempeño. Los indicadores de desempeño fueron obtenidos a partir del análisis de muestras del alimento, los lodos, y el jugo filtrado. El decantador centrífugo podría producir una torta de cachaza con baja humedad y bajo pol residual. Los ensayos de dispersión en el campo indicaron que la cachaza seca podría ser esparcida fácilmente en los camiones de lodos típicamente usados o en camiones diseñados específicamente para esparcir fertilizantes.
MEMBRANE FILTRATION OF CLARIFIED JUICE

By

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KEYWORDS: Membrane Filtration, Ceramic, Polymeric, Flux, Fouling.

Abstract

A MEMBRANE filtration plant using suitable micro or ultra-filtration membranes has the potential to significantly increase pan stage capacity and improve sugar quality. Previous investigations by SRI and others have shown that membranes will remove polysaccharides, turbidity and colloidal impurities and result in lower viscosity syrups and molasses. However, the conclusion from those investigations was that membrane filtration was not economically viable. A comprehensive assessment of current generation membrane technology was undertaken by SRI. With the aid of two pilot plants provided by Applexion and Koch Membrane Systems, extensive trials were conducted at an Australian factory using clarified juice at 80–98°C as feed to each pilot plant. Conditions were varied during the trials to examine the effect of a range of operating parameters on the filtering characteristics of each of the membranes. These parameters included feed temperature and pressure, flow velocity, soluble solids and impurity concentrations. The data were then combined to develop models to predict the filtration rate (or flux) that could be expected for nominated operating conditions. The models demonstrated very good agreement with the data collected during the trials. The trials also identified those membranes that provided the highest flux levels per unit area of membrane surface for a nominated set of conditions. Cleaning procedures were developed that ensured the water flux level was recovered following a clean-in-place process. Bulk samples of clarified juice and membrane filtered juice from each pilot were evaporated to syrup to quantify the gain in pan stage productivity that results from the removal of high molecular weight impurities by membrane filtration. The results are in general agreement with those published by other research groups.

Introduction

The sugar industry has long maintained an interest in the application of membrane filtration for both quality improvements and as a pre-treatment for processes to produce value-added products. Since the early work of Madsen (1973), sugar industry research organisations, commercial manufacturing and membrane supplying companies and sugar milling companies have been actively involved in the assessment of the benefits of membrane filtration systems and the installation and development of pilot plants into sugar factories.

Steindl (2001) provided a summary of available data from investigations undertaken at a number of sites around the world. Those investigations concluded that membranes would remove polysaccharides, turbidity and colloidal impurities and result in lower viscosity syrups and molasses, provide higher growth rates and improve exhaustion. The consensus from previous investigations undertaken in Australia was that membrane filtration was not economically viable due to high capital and operating costs. However, any economic analysis has to be based on the economic environment under which a particular factory is operating and the reasons why the installation of a membrane plant is being considered.
Despite the extensive investigations, the only two industrial installations of membrane technology in the cane sugar industry have occurred at Puunene Mill in Hawaii (Kwok et al., 1996) and at Felixton Mill, South Africa (Jensen et al., 2006).

This paper describes the recent assessment of current generation membranes undertaken by SRI.

Membrane trials

A comprehensive assessment of current generation membranes was undertaken by SRI using two pilot plants and ceramic tubular membranes provided by Applexion and spiral wound polymeric membranes provided by Applexion and Koch Membrane Systems (KMS). The assessment focused on the processing of clarified juice under a range of operating conditions to determine (a) the long-term sustainable flux levels and concentration factors that are possible for the different membrane configurations; and (b) improvements in juice quality and the derived downstream benefits. Suitable clean-in-place procedures were also examined using supplier recommended chemicals to maintain flux levels.

Bulk samples of clarified juice and membrane filtered juice were evaporated to syrup to assess the effects on pan stage productivity. The evaporated syrup was used in a laboratory vacuum pan to estimate changes in pan productivity and sugar quality improvements that could be achieved from membrane filtered juice.

Membrane pilot plants

Two pilot plants provided by Applexion and KMS were installed at an Australian mill for the trials. Schematics of the pilot plants are shown in Figures 1 and 2. Both plants contain (a) pre-filters fitted with 100 μm screens, (b) feed and recirculation pumps (c) feed buffer tank, (d) membrane modules (e) heat exchanger with thermostatically controlled valve and instrumentation.

Fig. 1—Schematic of the Applexion pilot plant (A - pre-filters; B - feed and recirculation pumps; C - feed buffer tank; D - membrane modules; and E - heat exchanger).

Both pilot plants were operated in a ‘feed and bleed’ mode. The Applexion unit operated by controlling the transverse membrane pressure (TMP) to maintain a relatively constant volumetric concentration factor (VCF) and permeate flux. TMP is defined as the force which drives liquid flow
through a cross flow membrane and equals the average of the feed and retentate pressures less the permeate pressure. The VCF is defined as the ratio of the volumetric flow rate of feed to the volumetric bleed rate of retentate in a continuous filtration system.

The retentate flow was adjusted using a pressure valve to control the VCF. The VCF was maintained by increasing the TMP (to a limit of 4 bar) to maintain the permeate rate as the membranes fouled. The KMS unit maintained a constant pressure drop between the feed inlet and the retentate outlet of the membrane modules for the duration of the run. This meant that, as the membranes fouled, the permeate flow slowly decreased.

Applexion provided several ceramic membranes to enable the investigation of the effects of the various flow channel configurations. KMS provided two spiral wound membranes including the sugar spiral (SS) and high yield sugar spiral (HYSS) that had never been applied to clarified juice applications previously. Both spiral membranes could be operated continuously on feed juice at 95°C. The polymeric membranes supplied by Applexion had lower operating temperature limits compared to the KMS membranes.

Details of the membranes investigated including the nominal molecular weight cut off (MWCO) or pore sizes and the filtration area of each membrane module are given in Table 1. Photographs of end views of some of the membranes are shown in Figures 3 and 4.

Trials were conducted using both pilots with clarified juice to assess membrane performance under a wide range of operating conditions including:

Temperature: 80 to 97°C
Recirculation flow velocity (Applexion): 3.9 to 5.2 m/s
Pressure drop (KMS - SS): 275 kPa
Pressure drop (KMS - HYSS): 415 kPa
VCF: 2 to 10X.
### Table 1—Details of the membranes tested during the trials.

<table>
<thead>
<tr>
<th>Membrane reference code</th>
<th>Membrane format</th>
<th>MWCO or pore size</th>
<th>Flow channel diameter, mm</th>
<th>Total surface area, m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Membranes supplied by Applexion</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IXP050F 4040</td>
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<td>50 kDa</td>
<td>n.a.</td>
<td>3.8</td>
</tr>
<tr>
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<td>150 kDa</td>
<td>n.a.</td>
<td>3.8</td>
</tr>
<tr>
<td>EW 4040</td>
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<td>90 kDa</td>
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<td>6.5</td>
</tr>
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<td>JX 3840C</td>
<td>Spiral organic</td>
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<td>5.5</td>
</tr>
<tr>
<td>KB-W-07 (300)</td>
<td>Ceramic</td>
<td>300 kDa</td>
<td>3.5</td>
<td>3.44</td>
</tr>
<tr>
<td>KB-W-07 (01)</td>
<td>Ceramic</td>
<td>0.1 µm</td>
<td>3.5</td>
<td>3.44</td>
</tr>
<tr>
<td>KB-T</td>
<td>Ceramic</td>
<td>0.1 µm</td>
<td>2.6</td>
<td>4.90</td>
</tr>
<tr>
<td>KB-W-T (045)</td>
<td>Ceramic</td>
<td>0.45 µm</td>
<td>3.5</td>
<td>3.44</td>
</tr>
<tr>
<td>KB-X</td>
<td>Ceramic</td>
<td>0.1 µm</td>
<td>6.0</td>
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<tr>
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<td>Spiral organic</td>
<td>50 kDa</td>
<td>N/A</td>
<td>5.00</td>
</tr>
</tbody>
</table>

Analyses

Daily composited samples of clarified juice feed, permeates and retentate were collected for analysis of sucrose, brix, starch, dextran, total polysaccharides and colour using standard ICUMSA methods. Snap samples of feed and permeate were also collected every three hours for analysis of brix, pH and turbidity (absorbance at 900 nm). Bulk samples of clarified juice and membrane
filtered juice from each pilot were evaporated to syrup in the laboratory to assess the effects on pan stage productivity. Sugar was then produced using the SRI laboratory vacuum pan under defined conditions and procedures to provide predictions of overall growth rate changes and pan stage productivity changes. The sugar produced in the laboratory pan was analysed to determine the sugar quality improvements that could be achieved after membrane filtration of the clarified juice.

The crystal growth rates were measured using the method developed by Broadfoot and Steindl (1980). The procedure was designed to measure growth rates under constant conditions of supersaturation and temperature for each growth experiment. Variations in growth rate would then be a function of viscosity and impurities in the mother liquor. The solubility coefficient of the syrup was determined by analysing the saturated syrup used for the growth rate experiments and calculating the solubility coefficient from the sucrose/water ratio. Viscosities were measured with a Brookfield viscometer and a No. 2 spindle at 67°C.

**Cleaning procedures**

Water flux levels were measured before, during and after cleaning procedures. The pre-trial water flux was used as a reference to gauge the effectiveness of the cleaning procedure and the chemicals used.

The membranes were cleaned in place (CIP) during the factory trials using the CIP recommendation of the membrane suppliers. For the Applexion pilot plant a cleaning cycle was initiated when the maximum TMP was reached and the flux started to decline. A cleaning cycle was initiated for the KMS pilot when the permeate flux had declined below a pre-set limit (around 50–60 L/m².h).

The hottest clean water available (~85°C) was used to flush the chemicals and rinse the membranes.

**Results**

The results of the membrane trials are presented for each pilot plant separately because of the different operating conditions. The trials were conducted over two crushing seasons but only average data are presented for the more promising membrane configurations.

**Filtration rate**

The obtainable flux through a membrane is not only dependent on the liquid properties and the type of membrane system used but also on the operating parameters and conditions. Basically, there is pressure controlled and mass transfer controlled regions for filtration according to Cheryan (1986). Flux is dependent and can be improved by a number of factors influencing these regions such as:

- Increasing operating pressure, as this influences the permeability through the membrane. This will also be limited by physical limits of the membrane and the increased cost required to operate at higher pressures.
- Decreasing viscosity and density of the feed material which is generally characterised by turbidity, dry substance, pH, operating temperature and VCF. In many cases, the viscosity and density of the feed material will be set by other factors.
- Increasing diffusivity which is affected by the turbulence and velocity (determined by the recirculating flow rate) through the membrane. The flow channel arrangement will also contribute to the turbulence of the flow.

**Permeate flux model**

To accommodate the range of conditions investigated and the huge amount of data collected, models were developed to allow flux predictions to be made about expected flux levels for any nominated condition. The statistically significant variables included in the models were temperature, cross-flow velocity of the feed stream (Applexion), pressure drop (KMS), brix of the
feed, and the target VCF. Viscosity was not included in the regression analysis because of the very limited range of values. Separate equations were developed for each membrane type. Average analyses of the clarified juice are:

- **Brix**: 18.2 (15.9–21.3)
- **Turbidity**: 9 (absorbance at 900 nm)
  
  26 NTU
- **pH**: 7.0

Regression analysis was used on the data to determine model parameters. Forward stepwise multiple regression was applied to obtain a simplified model expression. Only significant regression coefficients were retained in this model. The remaining regression coefficients of the simplified equation were determined with higher precision (according to student t test). This methodology for determining model parameters is similar to that used by Dornier et al. (1994) to establish the optimal conditions of cross-flow filtration. The form of the regression equation is as follows:

$$J = \alpha_1 + \alpha_2 \log(VCF) + \alpha_3 T + \alpha_4 u + \alpha_5 Bx$$  

where

- **J** = Permeate flux, L/m².h
- \(\alpha_x\) = Coefficients determined by regression
- **T** = Temperature, °C
- **u** = Velocity, m/s
- **Bx** = Brix

Predictions from this regression model provided excellent agreement with the raw data with \(R^2\) values greater than 0.96 in all cases. The results showed that the VCF and feed flow velocity were the most important variables affecting flux through the ceramic membranes.

A similar form of the regression equation was developed for the KMS membranes with the pressure drop substituted for the feed velocity and an additional term added to account for the flux decline over time. An example of the quality of fit between the actual data and the model prediction is shown in Figure 5 for one trial with the HYSS membranes.

![Figure 5](image-url)

**Fig. 5**—Example of measured flux and the model prediction of flux for the conditions of the test.
**Applexion pilot**

The permeate flux predictions for the ceramic membranes are shown in Figure 6. The ceramic membranes, except the KB-W-07 (045), generally gave reproducible results over the two years of trials, were easy to clean and maintain 'clean' flux levels and could handle operation at high VCF (up to 50X). The KB-W-07 (045) membranes experienced fouling and cleaning problems that resulted in a much lower flux being obtained than expected. It was assumed that the larger pore size became blocked more easily and remained blocked during the cleaning cycles.

Interestingly, the flux obtained for the KB-W-07 (300), KB-W-07 (01) and KB-T were very similar. The diameter of the feed channel in the standard KB-W-07 (01 and 300) is 3.5 mm and the nominal diameter of the KB-T channel is 2.6 mm. There was a risk that the tight corners of the oval shaped channels would result in a thicker boundary layer in these regions. However, the measured flux indicated that there was no decline in performance.

The benefit with this profile is that single elements provide 42% extra filter area for the same overall element dimensions. This has implications for the initial plant cost, the replacement cost of membranes and the operating costs.

The spiral organic membranes supplied by Applexion had lower temperature limits and produced much lower fluxes. When compared with the performance of the KMS membranes, the membranes provided by Applexion were not competitive.

**KMS pilot**

For the KMS membranes, the model can also be used to predict the flux level after a period of operation which is important when determining the required membrane area for a nominated feed rate. Figure 7 illustrates the model predictions for the following typical conditions:
Temperature: 96°C  
VCF: 10X  
Brix: 18.0 Bx  
Pressure drop (KMS - SS): 485 kPa  
Pressure drop (KMS - HYSS): 415 kPa

The KMS data in Figure 7 show the predicted flux over 22 hours of operation for both the SS and HYSS types.

![Fig. 7—Predicted flux for spiral organic membranes.](image)

**Permeate analyses**

The average improvement in juice quality achieved from membrane filtration of clarified juice is shown in Table 2.

The results indicate that there is not a lot of difference in separation performance between the two membrane types. The level of removal appears to be almost independent of the nominal pore size of the various membranes (for the types of impurities of interest) and may be an indication that the dynamic foulant layer on the surface of the membrane influences the efficiency of removal.

**Table 2**—Summary of juice analyses following membrane filtration.

<table>
<thead>
<tr>
<th>Pilot</th>
<th>Change (permeate – clarified juice)/clarified juice, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Colour</td>
</tr>
<tr>
<td>Applexion</td>
<td>−13</td>
</tr>
<tr>
<td>KMS</td>
<td>−13</td>
</tr>
</tbody>
</table>

If the data from all the Applexion plant trials are considered for each MWCO/ pore size range, there is a suggestion from Table 3 that more of the dextran passes through the membrane as the pore size increases. It is not so clear whether starch is similarly affected.
Table 3—Summary of the change in polysaccharide concentration for each size range for all the membranes supplied by Applexion.

<table>
<thead>
<tr>
<th>Polysaccharide</th>
<th>Initial conc. mg/kg</th>
<th>Change in concentration for each MWCO/pore size, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>50 kDa</td>
</tr>
<tr>
<td>Dextran</td>
<td>237</td>
<td>100</td>
</tr>
<tr>
<td>Starch</td>
<td>214</td>
<td>68</td>
</tr>
</tbody>
</table>

Pan stage productivity

The laboratory trials in the pilot pan determined that the increase in growth rate averaged 30% (from 221 μm/h to 287 μm/h). For a full pan cycle, the productivity improvement is about 15 to 23%. The improvement is similar to data presented from other investigations (Saska, 1997; Kwok, 1996). The improvement in pan productivity is due primarily to a reduction in viscosity of the syrup of 15 to 20%. This viscosity reduction was expected to flow through to the low grade C massecuite processing and provide an increase in sucrose recovery from final molasses.

The analytical results for the saturated syrup samples that were used to measure crystal growth rates indicate that the solubility coefficient of the feed syrup averaged 0.97 and it did not change following membrane filtration. The lower viscosity and higher growth rates of the syrups also resulted in the production of sugar with lower colour (~40%) reduced ash levels (~35%) and higher filterability (~17%).

Table 4—Summary of the results for the crystal growth rate studies.

<table>
<thead>
<tr>
<th>Sample source</th>
<th>Viscosity change, %</th>
<th>Growth rate change*, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applexion</td>
<td>−16.5</td>
<td>+17.3</td>
</tr>
<tr>
<td>KMS</td>
<td>−19.7</td>
<td>+17.6</td>
</tr>
</tbody>
</table>

*Calculated as (membrane filtered data – unfiltered data)/unfiltered data

Cleaning

Several cleaning procedures were assessed for their ability to recover to ‘near new’ flux levels. Initial CIP trials highlighted the importance of flushing and rinsing the membranes between cleaning cycles and indicated that high quality and hot temperature water improved the overall efficiency of the cleaning process. The detergent cleaning cycle was found to produce the most significant flux recovery.

During the trials, the water flux under standard operating conditions was monitored as an indication of the effectiveness of the CIP cycle and the condition of the membrane modules. After the usual decline in flux when the KMS membranes were first used, the water flux remained relatively constant over the period of the trials even when the membranes were stored for eight months between crushing seasons.

There was insufficient operating time with both the ceramics and the polymericas to determine the likely operating life of either type of membrane.

At the end of the trials, visual assessment and analysis of the water flux data for the KMS spirals were carried out which indicated no physical degradation of the membrane modules or blockages of the recirculating flow path.

Conclusions

A comprehensive assessment of the operation and performance of two membrane plants utilising a range of ultra and micro-filtration membranes was completed. The membrane types included spiral wound and tubular ceramic membranes covering a wide range of pore or MWCO sizes.
The 0.1 µm and the 300 kDa ceramic membrane elements provided the highest flux of the membranes tested. The factors that have a major influence on the flux rating are the feed properties including temperature, brix, and concentration of the impurities together with the feed velocity and pressure. The feed channel diameter and profile of the ceramic membranes only had a small influence on the achievable filtration rates. On the other hand, the width and the design of the spacer used to provide the feed channel in the KMS spiral membranes has a significant effect on the filtration rate.

Despite the larger pore sizes of the ceramic membranes, the separation efficiencies were similar to those achieved with the much tighter spiral membranes from KMS. It was assumed that the dynamic foulant layer played a major role in separating high molecular weight impurities from the juice stream.

The studies have shown that the ability to separate impurities from the juice was similar for both the ceramic and spiral membranes. The average reduction in impurity concentration is summarised as follows: colour 13%, turbidity 99%, polysaccharides 83%, starch 56%, and dextran 90%. As well, the membrane filtration of clarified juice led to improvements in downstream processes including an increase in crystal growth rate of 15 to 23% resulting from the reduction in viscosity of the syrup by 15 to 20%. The lower viscosity and higher growth rates of the syrups also result in the production of sugar of lower colour (~40%), reduced ash levels (~35%) and higher filterability (~17%).

A range of operating conditions was applied to each pilot. These data were then used to develop prediction models for each type of membrane. The fit to the experimental data was excellent. The models provide a useful tool to determine flux levels through each of the membrane types for a wide range of possible operating conditions.

Acknowledgements

The funding provided by the Sugar Research and Development Corporation and a syndicate of Australian sugar mills is acknowledged. The assistance provided by both Applexion and Koch Membrane Systems was extremely important to the success of the project.

REFERENCES


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FILTRATION MEMBRANAIRE DE JUS DE CLARIFICATION

Par
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MOTS-CLEFS: Filtration sur Membrane, Céramiques, Polymères, Flux, Encrassement.

Résumé
UNE UNITE de filtration sur membrane à l'aide de membranes micro- ou ultra-filtration a le potentiel d’augmenter la capacité des cuites et d’améliorer la qualité du sucre. Des travaux précédentes par le SRI et d'autres ont montrés que les membranes enleverent les polysaccharides, la turbidité et les impuretés colloïdales, et donnent des sirops et mélasses avec des viscosités plus faibles. Cependant, la conclusion de ces enquêtes a été que la filtration membranaire n’était pas économiquement viable. Une évaluation complète de la technologie des membranes de la génération actuelle a été entreprise par SRI. À l'aide de deux systemes pilotes provenant de Membrane Koch et d’Applexion, des essais ont été effectués dans une usine australienne avec du jus clarifie à 80–98 ° C alimentant chaque unite. Les conditions ont été variées durant les essais afin d'examiner l'effet d'une gamme de paramètres d'exploitation sur les caractéristiques de filtrage de chacune des membranes. Ces paramètres sont la température et pression de l’alimentation, la vitesse du jus, les solides solubles et la concentration des impuretés. Les données ont été ensuite combinées dans des modèles afin de prédire le taux de filtration (ou flux) pour les conditions d'exploitation désignées. Les modèles donnent un très bon accord avec les données recueillies durant les essais. Les essais ont également identifiés les membranes qui fournissent les plus hauts niveaux de flux par unité de surface de membrane pour des conditions spécifiques. Des procédures de nettoyage ont été mises au point et le flux d'eau a été retrouve après un processus de nettoyage en place. Des échantillons de jus de clarification et de jus filtré par les membranes de chaque pilote ont été évaporés pour produire du sirop, afin de quantifier le gain de productivité qui résulte aux cuites grace a l'élimination des impuretés de haut poids moléculaire par filtration sur membrane. Les résultats sont en accord avec ceux publiés par d'autres groupes de recherche.
FILTRACION CON MEMBRANAS DE JUGO CLARIFICADO

Por

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PALABRAS CLAVES: Filtración con Membranas, Membranas Cerámicas, Membranas Poliméricas, Flux, Incrustaciones.

Resumen

El uso de micro o ultrafiltración con membranas tiene el potencial de incrementar significativamente la capacidad de los tachos y mejorar la calidad del azúcar. Investigaciones anteriores realizadas por el SRI y otros investigadores han mostrado que las membranas remueven polisacáridos, turbiedad e impurezas coloidales, disminuyendo la viscosidad de las meladuras y mieles. Sin embargo, estos estudios han concluido que el uso de membranas no es una alternativa económicamente viable. Una valoración comprensiva de la tecnología actual en membranas fue realizada por el SRI usando dos plantas piloto suministradas por Applexion y Koch Membrane Systems. Se realizaron una serie de ensayos en un ingenio australiano, alimentando a cada planta piloto jugo clarificado a una temperatura entre 80 y 98°C. Durante los ensayos se variaron algunas condiciones para evaluar efecto de variaciones en los parámetros de operación sobre las características filtrantes de cada una de las membranas. Estos parámetros incluyeron la temperatura y presión del alimento, la velocidad del flujo, y la concentración de sólidos solubles e insolubles. Los resultados obtenidos fueron usados en un modelo para predecir la velocidad de filtración que podría ser esperada para unas condiciones de operación determinadas. Los modelos mostraron una muy buena correlación con los datos recolectados en los ensayos. Se identificaron para unas condiciones de operación determinadas aquellas membranas que presentaron el mayor nivel de flujo por unidad de área de membrana (flux). Se desarrolló un proceso de limpieza para asegurar que el agua utilizada en la limpieza de la membrana fuera recuperada en el mismo lugar de su uso. Se concentraron hasta meladura muestras de jugo clarificado filtrado y sin filtrar de cada una de las dos plantas piloto para cuantificar la ganancia en la productividad en la etapa de tachos como resultado de la remoción de impurezas de alto peso molecular durante la filtración con membranas. Los resultados obtenidos coinciden en general con aquellos obtenidos por otros grupos de investigación.
THE IMPLEMENTATION OF A DRYER/COOLER CONVERSION AND SHORT RESIDENCE TIME CONDITIONING SYSTEM FOR REFINED SUGAR

By

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KEYWORDS: Sugar, Dryer, Cooler, Conditioning.

Abstract

The rotary sugar dryer/cooler at Central Azucarera Don Pedro (CADP) refinery (Philippines) has been upgraded and a short residence time conditioning system has been installed through 2008–2009 to resolve hard caking issues being experienced in stored 50 kg sugar bags. This paper describes the modifications undertaken and the results achieved in resolving the caking issues. The reconfiguration and automation of the dryer/cooler and the installation of short residence time conditioning (eight hour conditioning period) provided a simple, low capital cost and low operating cost resolution to the caking issues previously encountered at the refinery, compared to alternatives. The reconfiguration and automation of the rotary dryer/cooler has reduced both power and steam consumption and allowed a significant increase in capacity, despite retaining the same rotary shell, fans, scrubber and air heater. The increased performance has eliminated the need for a fluidised bed cooler that was previously under consideration for purchase by the refinery. Since modification, the refinery has completely eliminated hard caking of refined sugar. There has been no need to remelt and recycle bags of sugar due to hard caking.

Introduction

Central Azucarera Don Pedro (CADP) refinery in the Philippines is a relatively new refinery (commissioned February 1994) and was initially rated at 550 tonnes refined sugar/day when built. After expanding twice, it is currently producing 900 tonnes/day (mostly in 50 kg bags).

Over recent years, problems were experienced with hard caking of some of the sugar produced (which is stored in 50 kg bags). This caking was severe around the edges of the bags with a thick, rock-hard crust forming only days after production of the sugar.

The refinery was considering the installation of a fluidised bed cooler for refined sugar, to be located downstream of the existing co-current hot air and counter-current cold air rotary dryer/cooler.

Options of conventional sugar conditioning were also investigated, though the capital involved was substantial and little comfort could be gained that the desired outcome would be achieved (based upon performance of recently installed conventional conditioning systems in the SE Asian region).

Sugar Technology International (STI) offered a solution to CADP which involved the uprating and upgrading of their rotary dryer/cooler and the installation of short residence time conditioning facilities.
Steps to conditioned sugar

To produce well conditioned sugar, it is believed that four key steps are involved:

1. Pan stage operations need to provide consistent grain size with low CV and few agglomerates,
2. The centrifuging step needs to achieve good purging and have no massecuite balls or wet lumps,
3. The drying step needs to be as slow as practical to minimise the quantity of sucrose in the amorphous state, and deliver sugar of appropriate moisture content and temperature, and finally,
4. The conditioning step needs to crystallise the excess sucrose held in the film around the crystal so the film is at equilibrium with its surroundings.

Of these steps, the first two relate purely to good refinery operating practice and will not be covered further. The CADP sugar refinery was already achieving good pan stage and centrifugal performance so these areas were not the cause of the hard caking that was observed.

This paper deals with the last two steps of achieving well conditioned sugar; drying and conditioning. The drying modifications at CADP are installed and commissioned and results are presented; however, at the time of writing, the conditioning system is under construction and not yet commissioned. It is the intention to discuss the conditioning system results at the ISSCT oral presentation.

Drying

The rotary dryer/cooler is an important part within the broader series of processing steps required to achieve well conditioned sugar that is free of caking problems.

The contribution of the drying step to potential caking issues is well established in the technical literature, but often over-looked within sugar refineries. It should be recognised that the drying step creates the problem of a supersaturated or amorphous sugar film around each crystal that the subsequent conditioning step must resolve.

In the drying step, the obvious goals are to consistently produce sugar of the desired moisture content and temperature. We contend that a more subtle goal is to prolong the drying step within the dryer to allow the greatest opportunity for crystallisation of sucrose within the film around each crystal.

While it is unrealistic to completely crystallise the sucrose within the film (such that the film leaves in a saturated state), to the extent that we can crystallise sucrose during drying, we minimise the quantity of sucrose in the amorphous film around each crystal and hence the task to be undertaken during downstream conditioning operations.

The major mechanism by which we moderate the rate at which drying occurs in the feed end of the dryer is to reduce the air flow rate and temperature. Reduced air flow leads to increased humidity in the exhaust from the dryer and thus a reduction in the driving force for evaporation.

It is interesting to contrast this approach with the earlier operations of this dryer when it used co-current hot air followed by counter-current cooling air flow. In that original configuration, co-current hot air (typically 90–100°C) was used in the sugar feed end of the dryer. Such air has an extraordinarily low relative humidity and sugar can be expected to lose moisture extremely rapidly under such conditions.

Other dryer types commonly used in various parts of the world similarly incorporate heated, extremely low RH air to perform drying (e.g. rotary louver, twin rotary drum and fluidised bed dryers). Of these, the speed with which moisture is removed is probably highest in the fluidised bed dryers.
Details of conversion of rotary dryer/cooler

Modifications to the rotary dryer/cooler involved a re-configuration to purely counter-current air flow, re-flighting of the drum to achieve a significant increase in capacity and the installation of instrumentation and controls to manipulate the dryer operating conditions over the entire sugar flow range (0%–100% capacity). The major modifications are shown in the schematic diagrams in Figure 1 (before conversion) and Figure 2 (post conversion).

Fig. 1—Sugar dryer before conversion.

Fig. 2—Sugar dryer after conversion.
The conversion retained the original dryer/cooler drum, though the central air exit holes were blocked when converting to purely counter-current flow. The original ID fan and cool air fan were retained, though variable frequency drives were fitted to reduce the air flows to the desired values. The original steam heated air heat exchanger was relocated, and (part way through the season) 67% of the heat exchange area blocked off, with a smaller steam control valve fitted.

**Results of modifications**

At the time of writing this paper, the dryer/cooler modifications are complete and have been operating throughout the 2008/2009 season. The conditioning silo modifications discussed in the next section are nearing completion but are not yet operational. The results presented here clearly show the benefit derived from the dryer conversions alone.

The sugar storage facilities at CADP are formidable as is clear from Figure 3. This photograph was taken in June 2009 and shows the CADP warehouse approaching full capacity with 900,000 x 50 kg bags of sugar in storage. Such tall stacks provide significant compressive loads and provide a real test of the caking propensity of the sugar.

Figure 4 shows the hard lumping of sugar in bags prior to the dryer conversion—such lumps were hardest towards the outside of the sugar bags.

Specialised machines to compressively deform the bags (known as ‘lump breakers’) were deployed in an attempt to resolve the issues. It is understood such machines are utilised in countries such as Brazil and Thailand. Since modification, only soft caking is observed even after three months storage in deep stacks (see Figure 5).

The lump breaker machines have not been in use for the entire 2009 season. The soft caking experienced after conversion readily breaks up in the normal handling of bags.

Fig. 3—CADP store with 900,000 bags, June 2009.
Fig. 4—Hard lumps of sugar prior to conversion, March 2008.

Fig. 5—Sugar nature after the dryer conversion and storage for three months, July 2009.

The quantities of sugar remelted due to caking over the past five years at CADP are given in Table 1. The statistics exclude bags remelted due to physical damage to bags in handling.
Figures 6 and 7 provide details of dryer temperatures before and after conversion. The air preheat temperature can be seen to be reduced during the year to the values recommended. This was achieved part-way through the season, when 67% of the air heater area was blocked off and a smaller steam control valve fitted to improve control. Note that, with the low counter-current air flow, hot air in the sugar discharge end of the dryer only has limited ability to heat the sugar, so the sugar outlet temperature after conversion is not increased.

The moisture content of the product sugar (by gravimetric determination) is seen to rise from the before modification period to after (though still within specification), yet the product sugar exhibits dramatically reduced caking propensity. This underlines the fact that moisture content in isolation is not a measure of the degree of conditioning or caking propensity (as discussed further in the conditioning section).

![Fig. 6—Inlet air and product sugar temperatures.](image)

![Fig. 7—Moisture content of sugar product.](image)
The elimination of hard caking of sugar through dryer modifications alone has been demonstrated. The sugar does still exhibit soft caking that breaks up readily in normal bag handling operations. This soft caking tendency will be addressed with the commissioning of the SRTC system.

The test through the 2008–09 season has been particularly good as many bags have been stored over several months in tall stockpiles without caking.

**Conditioning of refined sugar**

The means of assessing the ‘condition’ of sugar has been the subject of much debate over many years. Some refinery staff maintain that the moisture content of sugar can be used as a measurement of the degree of conditioning and that moisture removal is the primary aim of conditioning (Rein, 2007). While conditioning is often associated with a small reduction in moisture content, moisture content does not imply the state of conditioning, irrespective of how the moisture content has been measured.

In the conditioning of sugar, we maintain that the key goal is to crystallise sucrose that is held in a supersaturated state within the amorphous layer. By doing so, the later uncontrolled crystallisation of this sucrose is avoided. It is the crystallisation of sucrose at the contact points of sugar crystals leading to intercrystalline bridging that is caking.

Sugar moisture measurement is complicated by the known influence of supersaturated films on the moisture content as determined by conventional laboratory drying tests (Rein, 2007). Karl Fischer analysis of moisture is recognised as being a more accurate moisture determination than gravimetric techniques, but such equipment is not commonly available in refinery laboratories.

With highly supersaturated films, a significant proportion of the water is ‘bound’ and will not be detected during gravimetric analysis. With crystallisation of sucrose in the supersaturated film, bound water is converted to free water.

This is exemplified by the observation that the gravimetric moisture content of sugar can as much as double simply by storing the freshly dried sugar in a sealed container (Schmalz and Stroebel, 2004).

The observed ‘creation’ of moisture adds to the mystique of sugar conditioning but is quite easily explained in terms of the reduced activity of water in supersaturated films of unconditioned sugar.

In modelling of sugar dryers and sugar conditioning systems, the scientific means by which the ‘availability’ of water is expressed is by calculating the activity of water. The activity of water is simply the vapour pressure expressed by the water in a film divided by the vapour pressure that would be exerted by pure water at the same temperature.

If a supersaturated film has a water activity of 0.2, then it will be in equilibrium with air at the same temperature if the air RH is 20%. Water activity is useful because it can mathematically describe the varying ‘availability’ of water without resorting to a ‘bound water’ versus ‘free water’ classification.

The quantity of sucrose that is contained in a supersaturated film can be used to rank the caking potential of sugar as shown in Table 1.

The table below demonstrates that while the goal of a conditioned sugar is to achieve a nearly saturated film with low moisture content, knowing just the moisture content (however measured) is not sufficient to judge if conditioning has been completed.

In practice, no matter how well conditioned, it is always possible to induce caking by subjecting sugar to extreme treatment (e.g. gross wetting and partial dissolution followed by drying). In normal operations, however, having only thin films around crystals that are nearly saturated provides the least quantity of sucrose in solution that can form bridges.
Through the simulation of evaporation, heat transfer and crystallisation processes with a sugar dryer (Tait et al., 1994), it is possible to predict the partial pressure of water vapour exerted by the sugar as it progresses through the dryer. Figure 8 shows the predicted partial pressure of water exerted by the sugar in 30 equal increments as it moves through the rotary dryer (highest vapour pressure and temperature at the sugar feed end). Also presented in Figure 8 is the vapour pressure exerted by water of varying activities.

It can be seen that the calculated water activity at the sugar feed end is significantly less than that for pure sucrose at saturation (which is about 0.82–0.84). This is due to the rapid evaporation and concurrent crystallisation occurring near the feed end of the dryer. For about the first 6 elements (i.e. about 20% of the flighted length), the crystallisation rate is able to keep pace with the onset of supersaturation due to both the removal of water and the reduction in temperature. For the balance of the dryer, however, the activity of water rapidly reduces as the kinetics of crystallisation fall away. For this simulation of a refined sugar dryer, a water activity just under 0.4 is predicted. This prediction seems consistent with published measurements (Schmalz and Stroebel, 2004) who quote water activities of 0.45–0.55 for sugar of <0.05% moisture content. The results of these
simulations and plant measurements confirm that air of 10%–20% RH (as used in conventional conditioning) would remove further water from this sugar in the already supersaturated state it leaves the dryer. For a macro-scale comparison, to understand the nature of the films being dealt with, the water activity of ‘Hard Candy’ is 0.20 to 0.35.

Details of short residence time conditioning installation

The STI SRTC system at CADP is achieved by fitting radial internal divider partitions in two existing silos as shown diagrammatically in Figure 9. The silos are capable of receiving sugar of different grades from the refinery. The three compartments within each silo will consecutively fill, condition and empty on a cycle. The fill time is nominally six hours, conditioning time of eight hours and a further 5–8 hours in which to empty the compartment before the next charge is due.

By this means, an essentially continuous flow of sugar to downstream packaging equipment is maintained despite the conditioning operation being conducted as a batch. A specialised refrigeration and control package is used to supply air at the required conditions to each silo. Air is only directed to one compartment per silo simultaneously.

Comparison of SRTC and conventional conditioning

It is informative to reflect upon the combination of factors that lead to conventional conditioning systems requiring the long residence times they do.

In a tall silo, there will be an appreciable pressure drop as air is blown through it. Compressing refrigerated air raises the partial pressure of water vapour within that air. To avoid problems with moisture pick-up in sugar against the inlet or against the walls/floor of the silo, it is necessary to prepare quite low RH air. As this air expands (pressure reduces), the RH falls further. Thus, if you build a tall silo, there is not much choice other than to pass low RH air through it.

If sugar continually enters and leaves the conditioning silo (and perhaps is recirculated on occasion), this further complicates the issue because unconditioned sugar is more ‘moisture hungry’
than conditioned sugar of the same true moisture content. When comparing sugars of the same moisture content, the water in conditioned sugar has a higher water activity because its vapour pressure is not so suppressed by the supersaturated conditions in the film.

In conventional conditioning (Rein, 2007), air of typically 10% to 20% RH is supplied to silos of 24 to 48 hours residence time at a specific air rate of 3 m$^3$/h.t of sugar. For a refinery producing 50 t/h refined sugar, this translates to storage of 1200 to 2400 tonnes and air flows of 3600 to 7200 m$^3$/h. Such air flows have the capacity to aggressively strip moisture from the film surrounding each crystal resulting in a low water activity.

The rate of sucrose crystallisation in a supersaturated film is extremely slow under conditions of low water activity (Broadfoot, 1980) because, while the supersaturation driving force for crystallisation has been enhanced by removing moisture, the mobility of molecules within the film is severely reduced and therefore the kinetics of crystallisation are reduced.

If a silo operates under conditions of low RH, then the sugar within it is destined to undergo slow, conventional conditioning. Under these conditions, long residence times are required (e.g. 48 to 72 hours).

The STI short residence time conditioning system conducts conditioning in a batch of sugar over a much shorter residence time (hours) compared to conventional sugar conditioning (days). The obvious advantage of this is that the physical size of silos and associated equipment is dramatically reduced.

The underlying principle of short residence time conditioning is that conditioning can be performed relatively quickly if:

- the highly supersaturated sugar film is first given moisture to lessen the degree of supersaturation;
- crystallisation is allowed to proceed rapidly under the resulting higher mobility/ lower viscosity/ lower supersaturation film environment; and
- then, as the water activity rises in the film, moisture is removed (generally slightly more moisture is removed than was ‘loaned’ in the first place).

Central to the concept of short residence time conditioning is the establishment and propagation of a moisture wave through a batch of sugar. While supersaturated conditions are retained throughout the passage of the moisture wave, at the peak of the wave, the degree of supersaturation in the film is significantly reduced compared to the highly supersaturated film on sugar that enters the silo from the dryer.

In Table 2, the contrasting paths of conventional conditioning and short residence time conditioning are highlighted.

<table>
<thead>
<tr>
<th>Water Activity of Film</th>
<th>0.1</th>
<th>Highly S'Satd</th>
<th>Conventional</th>
<th>High</th>
<th>SRTC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caking Potential</td>
<td>0.5</td>
<td>Moderately S'Satd</td>
<td>Low</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>0.7</td>
<td>Mildly S'Satd</td>
<td>Very Low</td>
<td>Low</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

Table 2—Caking potential highlighting alternate conditioning paths.
Conventional conditioning initially reduces moisture content flowed by slow crystallisation, while SRTC initially adds moisture before crystallising and drying under faster though moderate conditions. While the same net result is obtained, the kinetics of crystallisation along the SRTC path is dramatically faster.

It is fair to say that short residence time conditioning is considered somewhat controversial as it represents a radical departure from conventional conditioning operations. It is through the careful manipulation of moisture that the greatest gains in conditioning kinetics can be achieved. Ironically in sugar conditioning, it appears that when well handled, moisture can be your best friend, yet when poorly handled, it is your worst enemy.

REFERENCES


L'INTRODUCTION D'UN SECHEUR/REFROIDISSEUR ET D'UN SYSTEME DE CONDITIONNEMENT A COURT TEMPS DE SEJOUR POUR LE SUCRE RAFFINE

Par

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MOTS-CLEFS: Sécheur, Refroidisseur, Conditionnement.

Résumé

LE SECHEUR/REFROIDISSEUR pour le sucre à la raffinerie de CADP (Centrale Azucarera Don Pedro, Philippines) a été revalorise et un système de conditionnement a court temps de séjour a été installé en 2008–2009 pour résoudre les problèmes de prise de masse rencontrées dans des sacs (50 kg) de sucre stocké. On décrit les modifications effectuées et les résultats obtenus pour résoudre le problème de prise de mass. La reconfiguration et l'automatisation du sécheur/refroidisseur et l'installation de conditionnement a court temps de séjour (période de conditionnement de huit heures) a été une solution simple et de coût faible pour résoudre les problèmes de prise de masse à la raffinerie, par rapport aux alternatives. La reconfiguration et l'automatisation du sécheur/refroidisseur ont réduit la consommation d'énergie et de vapeur et ont permis une augmentation en capacité, tout en conservant le même tambour rotatif, les ventilateurs, l’équipement pour le lavage des gaz et le réchauffeur d’air. L’amélioration des performances a éliminé le besoin d’un refroidisseur a lit fluidisé, qui avait été considéré précédemment par la raffinerie. Depuis la modification, la raffinerie a complètement éliminé la prise de masse du sucre raffiné et il n'a pas été nécessaire de refondre et de recycler les sacs de sucre.
IMPLEMENTACION DE LAS MODIFICACIONES EN LA SECADORA/ENFRIADORA Y DE UN SISTEMA DE ACONDICIONAMIENTO DE CORTO TIEMPO DE RESIDENCIA

Por

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PALABRAS CLAVES: Azúcar, Enfriadora, Secadora, Acondicionamiento.

Resumen
EN EL CENTRAL Azucarero Don Pedro (CADP) una refinería ubicada en Filipinas, se realizaron modificaciones a la secadora/enfriadora rotatoria y se implementó un sistema de acondicionamiento de corto tiempo de residencia durante la zafra 2008–2009. Estas modificaciones fueron hechas con el fin de resolver los problemas de aterronamiento observados en azúcar refinada empacada en bolsas de 50 Kg. Este artículo describe las modificaciones realizadas y los resultados alcanzados en la solución del aterronamiento. La reconfiguración y automatización de la secadora/enfriadora y la instalación de un sistema de acondicionamiento con un tiempo de residencia de 8 h fue una solución simple, de bajo costo de capital y operación, para resolver los problemas de aterronamiento comparada con otras alternativas. La reconfiguración/automatización de la secadora/enfriadora redujo la potencia y el consumo de vapor y permitió significativos incrementos en capacidad a pesar de que la secadora conservó tanto la misma carcaza, como los ventiladores, el scrubber y el calentador de aire. El incremento en el desempeño de la secadora eliminó la necesidad de un enfriamiento en lecho fluidizado alternativa que había sido considerada en la refinería. A partir de la modificación, la refinería eliminó completamente el aterronamiento del azúcar refinado. No ha sido necesario derretir o reciclar azúcar debido a aterronamiento.
GC-MS AS A TOOL FOR CARBOHYDRATE ANALYSIS
IN A RESEARCH ENVIRONMENT

By
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KEYWORDS: Gas Chromatography, Mass Spectrometry, Silylation, Carbohydrate.

Abstract

Gas chromatography, coupled with mass spectrometry (GC-MS) as a detection technique, is a powerful analysis tool in the hands of the research chemist. The fundamentals of the technique and its application to the analysis of carbohydrates using volatile derivatives such as trimethylsilyl ethers are described. Mass fragmentation spectra are shown to be useful in indicating carbohydrate ring structure (pyranoside vs furanoside), the reducing nature of the saccharide and the type of some glycoside linkages. The use of methylation and hydrolysis (typically called methanolysis), followed by silylation and GC-MS analysis, is shown to be a useful technique to characterise oligomer and polymeric carbohydrate material (gums and films). The use of these techniques using model compounds and use in one of the Sugar Milling Research Institute’s research programs will be discussed.

Introduction

The new Research Strategy of the Sugar Milling Research Institute (SMRI) has resulted in the creation of SMRI Strategic Research Thrust Areas and the move toward a medium-to-long term research focus (Dewar and Davis, 2007). To enable this shift in focus and achieve the required outcomes requires a commitment to both human and physical resources. As part of this resourcing, the SMRI has invested in new equipment including a gas chromatograph coupled to a mass spectrometer (GC-MS). This is an established analytical tool for obtaining both compound separation within a mixture and structural information on the separated organic compounds. It is used routinely in environmental analysis, forensics (profiling for drugs of abuse), arson analysis, food contamination and for identification and characterisation in the development of new pharmaceuticals.

The coupling of a mass spectrometer as a detector to a gas chromatograph was developed during the 1950s and 1960s (Gohlke and McLafferty, 1993). However, the type and size of the mass spectrometers available precluded their use in routine analysis. It was not until the 1980s, with the advent of the personal computer, that ‘benchtop’ instruments became available and the routine use of GC-MS became commonplace.

Since carbohydrates are thermally unstable, GC is an unsuitable method of analysis, unless the carbohydrate can be modified to make it volatile. The preparation of volatile derivatives such as methyl ethers, acetates and trimethylsilyl (TMSi) ethers was shown to be amenable to GC analysis (McInnes et al., 1958; Gunner et al, 1961; Sweeley et al, 1963).

This development was followed by the use of GC-MS in carbohydrate structural and identification research (DeJongh et al., 1969). Advances in GC-MS equipment and columns have resulted in the method becoming useful in compositional and structural analysis of monosaccharides, oligomers and polymers, especially in the environmental and life sciences fields.
Examples of the diverse use of the method include differentiation of strains of *Streptococcus pneumoniae* based on the capsular polysaccharide (Kim *et al.*, 2005), the identification and quantification of chitin in support of dating in the fossil record (Flannery *et al.*, 2001) and the analysis of plant gums used in works of art to check for forgeries (Bonaduce, 2007). This paper serves as an introduction to the technique and its use within a sugar research environment.

**Experimental**

Samples were prepared using the following methods.

**Permethylation**

Carbohydrate polymers were permethylated using the method of Laine *et al.* (2002). About 20 mg of ground sodium hydroxide and 0.1 mL of methyl iodide were added to 3–5 mg of the oligo- or polysaccharide sample in 0.5 mL dry dimethylsulfoxide. The sample was kept for 30 minutes in an ultrasonic bath at room temperature. Water was added and the mixture was extracted with dichloromethane (1 mL). The organic phase was separated, re-extracted with water, dried (anhydrous sodium sulfate) and evaporated to dryness with a stream of nitrogen at room temperature.

**Methanolysis**

Monosaccharides, permethylated carbohydrate polymers and carbohydrate polymers for compositional analysis were hydrolysed and methylated using the methanolysis method of Ciucanu and Caprita (2007). A solution of 2 M HCl/methanol was prepared by slow addition of 16 mL acetylchloride to dry methanol so that the final volume of the mixture was 100 mL. An aliquot of this solution (2 mL) was added to the sample (either from the previous step or 3–5 mg) in a Reacti-vial and sealed with a Teflon seal. The samples were heated in a ‘hot-block’ at 80°C for 16 h. After cooling, 5 μL of a sorbitol solution (100 mg / 100 mL in methanol) was added to the reaction mixture as an internal standard. The samples were evaporated to dryness using a stream of nitrogen at room temperature.

**Silylation**

The methylated sugars from the previous steps were silylated prior to analysis using a modification of the SMRI method (Anon, 2005a).

**GC-MS Conditions**

The derivatised sugars were separated on a Varian CP3800 GC equipped with a CP8400 autosampler. A Varian FactorFour VF-5ms (crosslinked 5% phenyl-methyl siloxane) column (30 m x 0.25 mm ID with DF=0.25 film thickness) was used. Column flow was set to 1.0 mL/min using helium as the carrier gas. The temperature program started with a temperature of 140°C held for 1 minute, a ramp of 2°C per minute to 218°C, followed by a ramp of 10°C per minute to 280°C. The final hold was two minutes. Injection temperature was 280°C with a splitless injection of 1 μL. The transfer line was held at 280°C and the mass spectrometer had a delay of five minutes. Data were collected over a range of m/z 40–650.

**Discussion**

**Basics of a GC-MS**

A GC-MS consists of four components (Figure 1). A sample containing a mixture of compounds of interest is separated in a GC column. As the separated volatile compounds elute from the column, they are bombarded with electrons within an ion-source in a process termed ionisation. These energetic electrons cause the compound to disintegrate and produce a mixture of positively charged ions in the gas phase. Provided the ionisation occurs under the same conditions, the disintegration will be reproducible. The resultant mixture of ions is accelerated into an analyser where they are separated and sorted from each other according to their mass-to-charge (m/z) ratio...
by manipulation of electrical fields. The sorted ions are collected by a detector and converted to a proportiona
tional electrical current. The data system records the magnitude of these electrical signals as a function of m/z and converts this information into a mass spectrum. The three MS components (ion source, analyser and detector) are housed within a vacuum system to minimise interaction with other molecules.

[Diagram of GC mass spectrometer]

A mass spectrum is a graph of ion intensity as a function of m/z ratio and is often depicted as a simple histogram (shown in Figure 2 for carbon dioxide). This record of ions and their intensities serve to establish the molecular weight and structure of the compound being analysed.

[Graph of mass spectrum of carbon dioxide]

As the CO$_2$ molecule enters the ion source, the electron beam ‘smashes’ some of the CO$_2$ molecules into ionised fragments; all of which are positively charged. The ionised CO$_2^+$ molecule (known as the molecular ion) appears at m/z 44 (the molecular mass of CO$_2$). The ionised fragments appear in the spectrum at m/z values less than the molecular ion.

Cleavage of a carbon-oxygen bond in the molecular ion to produce ionised carbon monoxide (CO$^+$) or ionised atomic oxygen (O$^+$) results in the fragment ions at m/z 28 and 16 respectively. The loss of two neutral oxygen atoms from the CO$_2$ results in an additional fragment at m/z 12 for carbon (C$^+)$.

There are different designs of mass spectrometer analysers, including quadrupoles, ion-traps, magnetic sectors and time-of-flight (TOF). They can not only be interfaced with GCs but can be
used as stand-alone instruments, connected to liquid chromatographs (LC-MS) or inductively coupled plasma spectrophotometers (ICP-MS).

**Analysis of sugars by GC**

A monosaccharide is classified as a triose, tetrose, pentose or hexose according to the number of carbon atoms in the molecule (three, four, five or six). The sugar may have an aldehyde or ketone group attached and these sugars are then termed aldoses or ketoses. Glucose is an example of an aldohexose while fructose is an example of a ketohexose. It can also be shown that monosaccharides can form a ring structure at the aldehyde or ketone. The formation of the ring produces an asymmetric carbon which gives rise to two isomeric forms of the sugar known as the α- and the β- anomers (Figure 3).

![Fig. 3—Anomeric forms of D-arabinose.](image)

A fundamental requirement for the separation and analysis of carbohydrates by GC is that they must be thermally stable and volatile. Carbohydrates must therefore be converted into stable, volatile compounds prior to chromatography. Suitable derivatives can be obtained in a reasonable time using silylation reagents such as hexamethyldisilazane. After silylation, the chromatogram will show multiple peaks of the α- and the β- anomers of the pyranose and furanose rings (Figure 4).

![Fig. 4—GC chromatogram showing separation of TMSi arabinose derivatives showing α- and β- anomers of the pyranoside and furanoside forms.](image)
Multiple mass spectra can be taken across each peak as it elutes from the column. The pertinent features of the mass spectra of the TMSi derivatised sugars are seen in Figure 5. No molecular ion at m/z 438 will be seen for the TMSi derivatised arabinose, as carbohydrate molecular ions are generally unstable. Very little difference can be seen between the \( \alpha \)- and \( \beta \)-furanoside spectra. These anomers have to be identified based on the difference in retention time on the GC column. However, there is a large difference between the pyranoside compared to the furanoside. The main peak at m/z 217 in the furanoside form is reduced in the pyranoside form, and the peaks at m/z 204 and 191 (not present in the furanoside spectrum) appear in the pyranoside form as seen in Figure 5. This characteristic difference in the mass spectrum can be used to distinguish between furanoside and pyranoside forms of a sugar – the presence of only m/z 217 indicates the presence of a furanoside form of the sugar. The peak at m/z 73 is due to the trimethylsilyl compound that replaced all the active hydrogens in the –OH groups in the sugar during derivatisation. Numerous GC and/or MS studies on TMSi carbohydrates have been reported and the mechanism of fragmentation elucidated (Kochetkov and Chizhov, 1966). Each peak in the mass spectrum can be assigned and used to help determine the structure of the sugar.

A direct silylation procedure produces multiple peaks (and thus mass spectra) for each sugar to be analysed. The number of glycoside peaks, their retention times and relative proportions are characteristic of each monosaccharide. If a mixture of sugars is analysed, a rather complex chromatogram results; however, the high efficiency provided by capillary GC columns generally permits satisfactory separations of the peaks to be achieved. Figure 6 shows a typical chromatogram for a mixture of TMSi sugars.
Compositional analysis of carbohydrate polymers

The analysis of carbohydrate polymers by GC is complicated by the reduced volatility of derivatised polymers.

The very high temperatures required to elute the compounds from the GC column simultaneously degrade and decompose the polymers.

Compositional analysis using GC-MS requires the polymer to be hydrolysed into its constituent sugars which can then be analysed as described.

Both chemical and enzymatic hydrolysis methods exist with the former being the ‘brute force’ method resulting in a mixture of monosaccharides, while the latter is very specific for a particular linkage and uses milder conditions.

The chemical method is ideal for compositional GC-MS preparation as all the sugars are released. A typical method would use an acidic solution of methanol with the sample being heated at 80°C for 16–20 hours—a method known as methanolysis (Bleton et al., 1996).

A methyl group attaches to the carbohydrate hydrolysed from the polymer. After complete hydrolysis, the sample is dried, silylated and analysed.

The resultant chromatogram will show most of the individual carbohydrates that made up the carbohydrate polymer. This process is shown for pullulan in Figure 7.

The mass spectrum of the two peaks shown in Figure 7 confirms that glucose is the only carbohydrate found in pullulan. Note also the presence of m/z fragments at 191, 204 and 217 indicating a pyranoside form of the ring.
Fig. 7—Methanalysis of pullulan showing hydrolysis and methylation at position 1 and resultant chromatogram after silylation showing only pyranoside glucose peaks.

If the carbohydrate were to contain sugars other than glucose, these would also be seen in the chromatogram and could be identified. An example would be xanthan gum (used to thicken sauces) which has a glucose backbone and a trisaccharide side chain consisting of mannose (with substituents) and glucuronic acid (Figure 8).

Fig. 8—Chromatogram from the methanalysis of xanthan gum showing the compositional sugars – glucose, mannose and glucuronic acid.
Structural analysis of carbohydrate polymers

The methanolysis method described above will only give the researcher compositional information about a carbohydrate polymer.

When studying the structure of an unknown polysaccharide, several questions arise: how many constituent monosaccharides does it contain, in what order are they linked; does it have a branched or linear structure; are the sugars in the pyranose or furanose form; and are the glycosidic linkages α- or β- or a mixture of the two?

There are many classical methods to determine the linkage between the sugars including methylation, the Barry degradation (Barry, 1943) and the Smith degradation (Smith and van Cleve, 1955) being the most common.

The aim of these techniques is to produce a series of derivatives which requires separation and can be used to identify the ring size and linkage position. These techniques are time consuming and require reasonable quantities of sample for analysis.

The resolving power and sensitivity of GC-MS techniques allows for very small quantities of these derivatives to be prepared and analysed.

The method adopted in our laboratories uses a methanolysis procedure based on the use of methyl iodide in dry dimethyl sulfoxide solution, extraction of the methylated polymer, followed by methanolysis and silylation (Laine et al., 2002).

Methylation adds a methyl group to all free hydroxyl groups on the sugar. Methanolysis will hydrolyse the sugar leaving a free hydroxyl group on the sugar which can then be silylated.

The position of the TMSi group will indicate where the sugar was joined to its neighbour. The structure of the sugar containing both methyl and TMSi groups can be determined by GC-MS and the position of the TMSi group will indicate the linkages on the particular sugar.

Dextran is a straight chain glucan consisting of α-1,6 glycosidic linkages between glucose molecules, with branches beginning from α-1,3 linkages (Figure 9, top).

Methylation of the dextran results in all the free hydrogens on the –OH groups being replaced by a methyl group (Step 1).

This is followed by methanolysis (Step 2) to yield the free methylated sugar with the methyl group on carbon 1 being in either the α- or the β- form (shown in the figure as –OMe horizontal on the page).

The other side of the bond now has a free –OH group which can be silylated (Step 3) to form the TMSi derivative.

Note that the glucose that had three other glucose units attached at the beginning of the branch now has two TMSi groups while the terminal glucose on the branch has no TMSi groups.

This results in three derivatised glucose units: 2,3,4-trimethyl-6-TMSi glucose, a lesser quantity of the terminal derivative 2,3,4,6-tetramethyl glucose and very small amounts of the linkage glucose, 2,4-dimethyl-3,6-TMSi derivative.
Fig. 9—Diagram showing the method of structural analysis using dextran as a model compound. The steps include methylation (Step 1), methanolysis (Step 2) and silylation (Step 3) to produce methylated, TMSi derivatives dependent on the position in the polymer.
The resultant chromatogram and two of the mass spectra from this scheme are shown in Figure 10. The mass spectra are quite different and the peaks easily identified.

![Chromatogram](image)

**Fig. 10**—Chromatogram resulting from the derivatization scheme shown in Figure 9 (top). Mass spectra of the 2,3,4,6-tetramethyl- and 2,3,4-trimethyl-6-TMSi glucose peaks (lower).
Based on the derivatives produced and the height of the peaks, it is possible to postulate that the dextran contains a small quantity of glucose that has linkages on the 3 and 6 position (based on the 2,4-dimethyl-3,6-TMSi derivative), a larger quantity of terminal glucose units (based on the 2,3,4,6-tetramethyl derivative) and most of the polymer consists of 1–6 linkages (based on the 2,3,4-trimethyl-6-TMSi derivative). Quantitation of the peaks is possible giving a ratio of each of the forms present.

In order to determine the retention time and mass spectra of each of the possible linkage combinations, a variety of di- and trisaccharides of known structure can be analysed by the method and a database of results accumulated. Table 1 is an abbreviated list of some of the compounds that can be used as examples for model linkages.

Table 1—Abbreviated list of compounds that can be used to illustrate model linkages for structural composition of carbohydrate polymers (coloured groups indicate different monosaccharides).

<table>
<thead>
<tr>
<th>Linkage</th>
<th>Methyl position</th>
<th>TMS position</th>
<th>Model compound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terminal xylose, furanose form</td>
<td>2,3,5</td>
<td>–</td>
<td>Xylose (methylated)</td>
</tr>
<tr>
<td>2-linked xylose</td>
<td>3,4</td>
<td>2</td>
<td>Xylotetrose</td>
</tr>
<tr>
<td>Terminal arabinose, furanose/pyranose form</td>
<td>2,3,5</td>
<td>–</td>
<td>Arabinose (methylated)</td>
</tr>
<tr>
<td>Terminal glucose, furanose form</td>
<td>2,3,5,6</td>
<td></td>
<td>Glucose (methylated)</td>
</tr>
<tr>
<td>Terminal glucose, pyranose form</td>
<td>2,4,5,6</td>
<td></td>
<td>Pullulan</td>
</tr>
<tr>
<td>3,6-linked glucose</td>
<td>2,4</td>
<td>3,6</td>
<td>Dextran</td>
</tr>
<tr>
<td>2,3,4,6-linked glucose</td>
<td>2,3,4,6</td>
<td></td>
<td>Glucose (silylated)</td>
</tr>
<tr>
<td>4-linked galactose</td>
<td>2,4,6</td>
<td>4</td>
<td>Lupin</td>
</tr>
<tr>
<td>6-linked galactose</td>
<td>2,3,4</td>
<td>6</td>
<td>Stachyose</td>
</tr>
</tbody>
</table>

The practical use of the techniques in carbohydrate research

As part of the strategic research thrust, SMRI has been investigating the phenomenon of refractory (‘hard-to-boil’) massecuites.

Polysaccharides (gums) have been implicated as a possible contributing factor to this problem (Koster et al., 1992; Duffaut and Godshall, 2004; Eggleston and Cote, 2008) and, therefore, SMRI researchers wished to study the composition of the polysaccharides in the refractory materials.

The initial study included eight samples of refractory and normal B molasses collected from four South African mills. The massecuites were deemed normal or refractory by mill personnel based on low molasses exhaustions which subsequently resulted in high target purity differences and recovery losses.

Analyses on the samples included haze dextran, gums, starch, consistency, sulfated ash, sucrose, glucose, fructose and brix. The gums were isolated using the SASTA method for gum determination (Anon, 2005b) and the composition analysed using methanolysis and silylation as described.

Selected results are shown in Table 2 while a chromatographic comparison between one of the normal and abnormal massecuite pairs is shown in Figure 11.
Table 2—Results of selected analyses of some refractory B molasses from three South African mills.

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Mill 1 Normal</th>
<th>Mill 1 Refractory</th>
<th>Mill 2 Normal</th>
<th>Mill 2 Refractory</th>
<th>Mill 3 Normal</th>
<th>Mill 3 Refractory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consistency (Pa.s)</td>
<td>0.33</td>
<td>3.31</td>
<td>0.8</td>
<td>3.46</td>
<td>0.58</td>
<td>1.40</td>
</tr>
<tr>
<td>Gums (ppm)</td>
<td>13 100</td>
<td>20 100</td>
<td>11 300</td>
<td>19 100</td>
<td>11 300</td>
<td>18 500</td>
</tr>
<tr>
<td>Arabinose</td>
<td>3.5</td>
<td>1.7</td>
<td>4.8</td>
<td>1.3</td>
<td>5.1</td>
<td>2.7</td>
</tr>
<tr>
<td>Xylose</td>
<td>3.8</td>
<td>2.4</td>
<td>7.1</td>
<td>2.2</td>
<td>7.2</td>
<td>4.2</td>
</tr>
<tr>
<td>Mannose</td>
<td>3.9</td>
<td>4.8</td>
<td>4.7</td>
<td>4.7</td>
<td>5.7</td>
<td>7.3</td>
</tr>
<tr>
<td>Galactose</td>
<td>15.1</td>
<td>10.1</td>
<td>17.4</td>
<td>9.0</td>
<td>17.3</td>
<td>11.8</td>
</tr>
<tr>
<td>Glucose</td>
<td>73.7</td>
<td>80.9</td>
<td>66.0</td>
<td>82.8</td>
<td>64.7</td>
<td>74.0</td>
</tr>
<tr>
<td>Gluconic acid</td>
<td>0.0</td>
<td>0.0</td>
<td>0.1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

The refractory samples showed both increased consistency and concentration of gums compared to the normal samples. GC-MS analysis of the gums showed that, while all gum samples contained arabinose, mannose, galactose, glucose and traces of gluconic acid, the amount of arabinose, xylose, and galactose decreased in the ‘hard-to-boil’ samples while glucose and mannose increased. Structural analysis of the gums is continuing in an effort to understand the causes of this phenomenon.

Fig. 11—Chromatograms comparing a normal (upper) and ‘hard-to-boil’ massecuite (lower).

Conclusion
Gas chromatography, coupled with mass spectrometry as a detection technique, has been shown to be a powerful analysis tool. Although the fundamentals of the technique are easily understood, it is only with modern PC-based equipment that the applications have become commonplace. The application of the chemical derivatisation methods (methylation and
methanolysis), combined with the sensitivity and selectivity of the GC-MS instrument, is allowing a new understanding in research problems of oligomer and polymeric carbohydrate compounds within the SMRI research program and is complementary to other analysis methods.

REFERENCES


L’OUTIL GC-MS POUR L’ANALYSE DES HYDRATES DE CARBONE EN LABORATOIRE DE RECHERCHE

Par

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MOTS CLEFS: Chromatographie Gazeuse, Spectrométrie de Masse, Silylation, Hydrates de Carbone.

Résumé

La chromatographie en phase gazeuse associée à la spectrométrie de masse (GC-MS), comme technique de détection, est un outil important pour le chercheur. Les principes fondamentaux de la technique et son application à l'analyse des hydrates de carbone à l'aide de dérivés volatiles tels que les éthers de triméthylsilyl, sont décrits. Les spectres de masse des fragments sont utiles pour éclaircir la structure des glucides (pyranoside vs furanoside), la nature du saccharide et le type des liens glycosides. L'utilisation de la méthylation et de d'hydrolyse (généralement appelé methanolysis), suivie de silylation et de l’analyse par CPG-SM, est une technique utile pour caractériser les oligomères et les matériaux polymères glucides (gommes et films). L'utilisation de ces techniques avec des composés modèles et pour l'un des programmes de recherche du Sugar Milling Research Institute sera discuté.
GC-MS UNA HERRAMIENTA PARA EL ANALISIS DE CARBOHIDRATOS A NIVEL DE INVESTIGACION

Por

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PALABRAS CLAVES: Cromatografía de Gases, Espectrometría de Masas, Sililación, Carbohidratos.

Resumen
LA CROMATOGRAFÍA de gases acoplada con espectrometría de masas (GC-MS) utilizada como una técnica de detección, es una poderosa herramienta de análisis para investigaciones químicas. Los fundamentos de esta técnica de análisis así como su aplicación son descritos para el análisis de carbohidratos usando derivados volátiles tales como el trimetil silil éteres. Se presenta el fragmento de un espectro de masas que puede ser usado como un indicador de la estructura del anillo (piranosá vs furanosá) de los carbohidratos, ó para establecer la naturaleza reductora de los sacáridos como también para establecer el tipo de algunos enlaces glicosídicos. El uso de la metilación y la hidrólisis (típicamente conocida como metanólisis) seguido por sililación y análisis GC-MS se presenta como una herramienta útil para caracterizar carbohidratos tales como polímeros y oligómeros (gomas y películas). Se presenta el uso de estas técnicas usando un compuestos típicos y su aplicación en uno de los programas de investigación del Sugar Milling Research Institute.
STUDIES OF LONG-TERM STORAGE OF HIGH QUALITY RAW SUGAR

By

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KEYWORDS: VHP Sugar, Storage, VLC Sugar.

Abstract

AlTHOUGH existing contracts do not provide sufficient economic justification to increase raw sugar quality, the trend of manufacturing better quality raw sugar in the mills will likely continue. Relatively few studies have been conducted on storage of VHP (very high pol) and VLC (very low colour) sugars, especially when the storage period approaches 9–10 months. Monitoring of commercial sugar shipments indicated that, after an initial relatively safe period of storage, sugar colour might double or even triple in a short period of time. Large experimental piles of VHP and VLC sugar were monitored in two sugar mills with different crystallisation sequences (conventional and double magma) for two consecutive seasons. Temperature and relative humidity probes were placed up to 15 m inside the piles. Samples were taken periodically to evaluate the effects of storage conditions on colour, purity, invert content and other parameters. It was concluded that sugar of high quality stores better compared to conventional sugar. However, even VHP sugar can double its colour during long-term storage. Sampling near the surface of the sugar pile (up to 1.5 m inside the pile) is not representative of the bulk of sugar. It has been found that sugar temperature follows the ambient trend as deep as 3 m inside the pile. Sugar within 1.5 m of the surface that was not subjected to temperature increase stored well compared to sugar in the core of the pile. It is unclear what conditions trigger colour increase in storage. Changes in temperature profiles of raw sugar during storage in commercial warehouses indicate that some exothermic reactions take place in the core of the piles that result in colour increase and pol reduction. The reactions take place even when the initial sugar moisture and temperature meet the requirements accepted for safe storage (safety factor below 0.25 and temperature below 30°C). Lower sugar pH may be one of the reasons that makes sugar less stable in storage. Options of cooling sugar before or during the storage will be considered in future research.

Introduction

The increasing price of fossil fuels creates an impetus to manufacture better quality raw sugar in the mills that utilise renewable fuel (bagasse). In an analysis of impacts of high quality raw sugar on refinery parameters, Al Ghurair and Hikmat (2005) demonstrated that the transition from conventional raw sugar (98.4 pol and 3800 ICUMSA colour) to VHP sugar (99.4 pol and 800 ICUMSA colour) resulted in the elimination of the affination process, a reduction in low grade massecuite handling and consequent savings in energy and utilities. Various specifications of high quality raw sugar are used throughout the world resulting in different terminology. A detailed summary of the specifications and contracts can be found in Rein (2007).

Most Louisiana sugar mills use a conventional three boiling scheme and produce raw sugar within the range of specifications: pol 98.5–99.0 and colour 2000–3000 IU (pH 8.5). Several mills that use a ‘double magma’ boiling scheme have the capability of producing VHP and VLC sugar, but existing contracts do not provide sufficient motivation to do it. It is noteworthy that the values for colour measured at pH 8.5 are sometimes twice as high compared to values obtained at pH 7.
(following ICUMSA procedure). Louisiana millers produce sugar that is close to VLC specifications if the standard ICUMSA procedure is applied. The VHP and VLC sugar specifications for the purpose of the current paper are: colour 2000 IU (pH 8.5) and polarisation exceeding 99.2.

Because of the relatively short grinding season in Louisiana, raw sugar may be stored for 9–10 months. Historic data on conventional quality sugar indicate that colour increases significantly during storage with a relatively low decrease in pol (Kochergin and Saska, 2008). A typical curve illustrating colour increase in storage of conventional sugar is shown in Figure 1. It is generally accepted that a correlation exists between the colour and pol of the raw sugars. The expectation is, therefore, that production of VHP sugar automatically results in VLC sugar. This statement may be valid for freshly produced sugar, but does not necessarily apply for stored sugars.

![Figure 1](image-url)  
**Fig. 1**—Colour increase in storage typical for Louisiana sugar mills; shipment dates range from November through September of the following year.

Figure 2 presents the data collected from four Louisiana mills during production and storage seasons. Although the trend line follows the expectations, the low value of the correlation coefficient indicates that colour-pol relationships have to be treated with caution.

Consequently, production of low colour sugar does not guarantee colour preservation during storage.

The majority of the information on changes in sugar quality during long-term storage is related to refined sugar where sugar is stored in silos and bins without contact with ambient air (Mikuš and Budiček, 1986).

Limited data are available on storage of raw sugar, especially of high quality. Early investigations of quality change of raw sugars in long-term storage (Kopfler, 1933) demonstrated four to five-fold colour increase after 6–7 months of storage of sugar with 97 pol and 0.6–0.7% moisture.

Preferential destruction of glucose observed in the tests implied microbiological origin of sugar deterioration. The present analysis of degraded sugar syrup collected from the floor of a raw sugar warehouse showed a fructose/glucose ratio of 2, confirming rapid destruction of glucose. In a discussion on raw sugar storage, Honig (1963) attributed sucrose deterioration to bacterial activity, emphasising the importance of producing low moisture sugar for good storability.
Information on long-term storage effects on high quality raw sugar is scarce. Interpolating between two extreme cases of storage of white and conventional raw sugar, it is logical to assume that high quality sugar would store without significant colour increase. Investigating storage behaviour of VHP sugar, Kimmerling (1975) reported that ‘with the exception of moisture pick-up in the crust and a very slight colour deterioration therein, no deleterious effects were observed on VHP sugar stored in the silo for six months’. However, no quantitative data, besides sugar moisture and ambient relative humidity, were presented. South African technologists reference storage of 99.3 pol sugar for 6 months with a colour increase of 5–20% (Rein, 2007). Chen and Chou (1993) referenced a Hawaiian report that VLC sugar could be stored safely at low moisture. Data on accelerated storage of raw sugar in small closed containers indicate that colour of VHP sugar can be increased by simply holding it at elevated temperature, e.g. 70°C (Kochergin and Saska, 2008). Any colour changes at this temperature would most likely have chemical rather than bacterial origins. Most researchers agree that the colour changes happen within the thin film of molasses surrounding the sugar crystals. Payne (1987) insists that colour changes are happening within sugar crystals as well. The rate of such changes would be conceivably slower than that in the molasses film.

The main goal of the current study was to monitor storage of VHP and VLC sugar in factory warehouses. It was important to assess if sugar specifications could be kept constant throughout the grinding and storage seasons.

**Experimental procedures**

**Grinding season 2007–08**

Enhanced washing procedures were used at two Louisiana sugar mills to produce VHP and VLC sugar. Both mills started production of higher quality sugar in the beginning of November, 2007. Sugar was allowed to stay in the warehouse for the maximum practical storage time (about 300 days) before shipping. Five thousand tonnes of VHP/ VLC sugar were produced at Mill A with a conventional three-boiling configuration. Mill B with a ‘double magma’ boiling configuration produced two smaller piles next to each other in the same warehouse. Each pile contained about 300 tonnes of VHP/VLC and conventional quality sugar, respectively. All produced sugar satisfied the safety factor requirements for storage (safety factor below 0.25). Sugar samples were taken every 3–4 weeks at three different depths from each pile, namely, top crust (15–20 mm), immediately under the top crust (>20 mm) and at a depth of 0.3–0.4 m. Each sugar sample was prepared by blending 5–6 samples taken from positions around the pile about 3 m apart.
auger was used to take samples from 0.3–0.4 m deep in each pile. It was difficult to obtain samples from larger depths due to friction. After several months of storage, another sampling procedure was added at Mill A. Samples were collected about 1.5–2 m inside the pile at the bottom using a front end loader. The following parameters were measured for each sample: pol, moisture, ash, fructose, glucose and colour at pH 7 and pH 8.5.

HOBO data loggers (model U12-011, Onset Computers, Bourne, MA, USA) were installed right above the surface of the pile and at 1.5 metres depth, respectively, to record temperature and relative humidity (RH). The sensor submerged in sugar was placed inside a perforated pipe covered with a porous plastic screen to protect the sensor from immediate contact with sugar. Thus, air parameters at equilibrium with raw sugar were measured. Battery operated sensors recorded the RH and temperature every two hours throughout the whole storage period.

**Grinding season 2008–09**

The test program was continued during the 2008–09 grinding season. Mill B (double magma boiling configuration) produced 5000 tonnes of VHP and VLC sugar in the beginning of November 2008 and stored it until June 2009. From the results of the previous season, it was difficult to conclude whether the samples were truly representative of the entire bulk of sugar in the pile. Sampling procedures were modified to obtain samples deeper into the pile. A gas-powered auger model EA-400 (Echo Inc., Lake Zurich, IL, USA) was used to obtain composite samples from a 1.5 m depth. The auger was driven into the sugar pile through an opening in the bottom of a stainless steel bucket. When the auger was slowly removed without changing rotation, the bucket gradually filled with sugar representing a 1.5 metre cross-section of the pile. Two samples were collected from different spots to produce a composite sample for analysis. The samples were analysed for pol, purity, ash, glucose, fructose, colour and moisture.

To evaluate temperature and RH changes in the core of the pile, five RH-temperature sensors were installed inside a sectioned 10 cm diameter pipe positioned according to the diagram in Figure 3. Four sections of the pipe at various depths had cut-outs covered with plastic screens. The sensors were located at the depths of 0, 3, 7, 5, 10 and 15 m, respectively. The probe at 0 m was monitoring ambient conditions. Recorded data were periodically downloaded to a computer through connected USB cables.

**Analytical procedures**

Standard ICUMSA procedures were followed for measuring sucrose polarisation, brix and conductivity ash. Sugar colour was analysed according to the ICUMSA Method GS1/3-7(2002) at pH 7.0, and at pH 8.5; the latter measurement is required by contracts accepted in the USA. Glucose and fructose were analysed using Dionex DX-500 HPLC with Carbopac PA-100 columns and a
pulsed amperometric detector following ICUMSA Method GS1/2/3-4(1998) with lactose as the internal standard. All HPLC measurements were performed in duplicate.

Sugar moisture was determined by drying at 105°C under vacuum, for four hours. Initially, sugar pH was measured at about 16 brix, which was a convenient dilution for colour measurement. As a result, sugar pH values were not recorded at constant brix.

Separate dilutions were made for samples obtained later in the season, and the measurements were performed at 50 brix.

Results and discussion

Grinding season 2007–08

Colour changes in the samples collected 0.3–0.4 m below the top crust are shown in Figure 4. As expected, sugar colour in Mill A (using conventional three-boiling scheme) was almost twice as high as in Mill B with a ‘double magma’ configuration, and was very close in quality to conventional sugar produced in Mill B.

Rates of colour rise were similar in both cases. Since sugar colour was expected to be kept at or below 2000 ICUMSA units (pH 8.5), the results at Mill A were slightly higher than desired. Little change was noticeable in colour of sugar stored at Mill B throughout the season.

Data demonstrated that additional washing in a ‘double magma’ configuration allows production and maintenance of the sugar quality within the desired limits. However, wash water requirements and the associated sugar losses need to be evaluated.

![Fig. 4—Colour changes during 2007–08 grinding season at 0.3–0.4 m depth and at 1.5 m depth).](image)

Measurements at different depths in the pile are illustrated by curves in Figure 5. In all cases, the colour of the top crust changed significantly, with the most pronounced effect after 3–4 months of storage. The first several months corresponded to the time of storage when the ambient temperature was lower than that of the sugar.
Fig. 5—Colour changes at various depths in VHP sugar (Mill B).

Top crust (about 15–20 mm) has higher colour and moisture than the rest of the sugar. The crust is formed of fine dust particles that settled after sugar slinging.

Measurements showed that product sugar crystals (800 µm) have four times less colour than the fine fraction (less than 250 µm).

The results in Figure 4 show changes in colour at various sampling depths at Mill B. Colour of sugar directly under the crust is no different from sugar at a 0.3–0.4 m depth.

The same trend was observed in all sampled piles. The crust appears to work as a protective layer; this phenomenon was also mentioned by Kimmerling (1975).

Depending on ambient conditions, crust may be very hard (observed in January and February) or soft, but always different from the rest of sugar.

The changes in ambient conditions (temperature and RH during the trials) are reflected in Figures 12 and 13.

A reduction in both sugar polarisation and apparent purity was observed in all stored samples (Figures 6 and 7). The pol of conventional sugar in Mill B was slightly higher than that in Mill A, although the rate of deterioration was similar. Differences in degradation rates are difficult to discern due to the data dispersion. However, the pol and purity drop of 0.3–0.4 points should be considered significant.

Changes in concentration of reducing sugars (Figure 8) do not reveal if sucrose deterioration was caused by inversion or degradation reactions that have gone further.

Trends in Figure 9 represent the ratio of fructose to glucose (F/G) in stored samples at various depths.

While the F/G ratio fluctuated around unity (which was expected for sugar inversion), the crust samples showed drastically different F/G ratios, consistently below this level, reaching a value of 0.3.

This indicates that fructose was preferentially consumed in browning reactions.
Fig. 6—Changes in sugar polarisation (depth of 0.3–0.4 m and 1.5 m).

Fig. 7—Changes in sugar purity (depths of 0.3–0.4 m and 1.5 m).
Fig. 8—Change in the concentration of reducing sugars (depths 0.3–0.4 m and 1.5 m).

Fig. 9—Fructose/glucose ratio at Mill A.
Changes were observed in sugar pH (Figure 10). Sugar pH was not routinely measured at the beginning of the storage period. The pH trend showed a gradual decrease toward the end of storage, coinciding with observed pol decreases. The lowest pH was observed in the regular sugar at Mill B, followed by samples at Mill A. Mill B VHP sugar was the closest to neutral pH. These were also the samples that showed minimal deterioration. It is difficult to discern if low initial pH might
cause enhanced sugar degradation. It is conceivable that low pH in the molasses film could gradually invert sugar causing a further pH decrease. Sucrose inversion consumes water but further degradation reactions actually release water, which should result in increased sucrose moisture. Moisture changes observed during the study (Figure 11) do not provide reliable support to this hypothesis. Moisture content of the samples is also influenced by water migration in and out of the pile. Analysis of highly deteriorated sugar samples always shows increased moisture content. Moisture levels in the crust increased as high as 1–2% at the end of storage.

Fig. 12—Temperature change inside and outside the sugar pile.

Fig. 13—Change in RH during storage period.
Analysis of daily records of RH and temperature indicates that the top several metres of sugar act as an ‘insulation’ layer, protecting the bulk from sudden temperature or humidity swings.

The monthly temperature averages represented in Figure 12 show temperatures 1.5 m inside the pile follow the temperature trend outside the pile quite closely (sugar gradually cooled down from an initial 30 to 20°C). When the ambient temperature increased, sugar temperature started to rise as well. However, it never reached the initial sugar temperature. The graph in Figure 13 illustrates a continuous increase of RH both inside and outside the sugar pile (Mill A).

Moisture transfer is a function of vapour pressure, which is closely approximated by absolute humidity. Thus, the difference between absolute humidity of ambient air and the air inside the pile can give an indication of the direction of moisture transfer. The values for absolute humidity in Table 1 were determined from a psychrometric chart based on RH and temperature readings for several points during storage.

<table>
<thead>
<tr>
<th>Table 1—Absolute humidity inside and outside the sugar pile.</th>
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<tr>
<td>Storage time, months</td>
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<tr>
<td>Abs. humidity at 1.5 m depth, kg H₂O/kg dry air</td>
</tr>
<tr>
<td>Abs. humidity of ambient air, kg H₂O/kg dry air</td>
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Initially, absolute humidity of air in equilibrium with sugar was higher than that of ambient air, which meant that sugar tended to release some moisture to the atmosphere which will be migrating out of the pile. Later in the season, sugar was unlikely to lose moisture, because ambient humidity is higher. Sugar moisture levels (Figure 11) did not vary much toward the end of the storage season.

**Grinding season 2008–09**

Analytical results listed in Table 2 show that sugar colour in the composite samples remained virtually unchanged during storage. However, the samples collected from the bottom of the pile before shipping showed that colour almost doubled.

<table>
<thead>
<tr>
<th>Table 2—Data from grinding season of 2008–2009.</th>
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<tr>
<td>Date</td>
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Samples taken during the loading/shipping of VHP pile 50 Bx
This may be explained by reviewing the temperature profiles presented in Figure 14. After an initial stable storage period, sugar temperatures started rising well above the initial values. The reading from 3 m inside the pile followed the ambient temperature trend (Figure 15). The greatest temperature rise was observed at the depths of 5 and 10 m. The probe located near the bottom of the pile floor measured a lower gradient due to heat transfer to a cooler floor surface.

Temperature rise in the pile and corresponding colour change imply that exothermic reactions take place even at low moisture and high pol. Relatively low pH was observed in all samples and no changes in pH were observed during the storage period. Fructose to glucose ratios were also different compared to results from the 2007–08 season. The fact that sugar as deep as 2 m inside the pile can store without deterioration implies that such conditions can be reproduced if mechanisms causing sugar degradation are better understood. The study will be continued with the emphasis on changes that need to be made to production to assure that high quality sugar can be stored reliably without deterioration.
Conclusions

- Sugar of high quality stores better compared to conventional sugar. However, even VHP sugar can double its colour during long-term storage.
- Sampling near the surface of the sugar pile (as deep as 1.5 m inside) is not representative of the bulk of sugar.
- It is unclear what conditions trigger colour increase in storage. Lower sugar pH may be one of the reasons that makes sugar less stable in storage.
- Sugar temperature follows the ambient trend as deep as 3 m inside the pile.
- Exothermic reactions take place inside the pile even when initial sugar moisture and temperature meet the requirements accepted for safe storage (safety factor below 0.25 and temperature below 30°C).
- Sugar within 1.5-m of the surface that was not subjected to temperature increase stored well compared to sugar in core of the pile. Options of cooling sugar before or during the storage will be considered in future research.

Acknowledgments

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ETUDES DE L’EMMAGASINAGE A LONG TERME DU SUCRE ROUX DE BONNE QUALITE

Par

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MOTS CLEFS: Sucre VHP, Emmagasinage, Sucre VLC

Résumé
BIEN QUE les contrats existants ne fournissent pas une justification économique suffisante pour améliorer la qualité du sucre brut, les usines continueront très probable à produire un sucre de bonne qualité. Relativement peu d'études ont été menées sur l’emmagasinage à long terme du VHP (pol très élevé) et des sucres VLC (couleur très faible), en particulier lorsque la période de stockage approche 9–10 mois. On a suivi les transports outre-mer de sucres commerciaux ; cela a indiqué que, après une période relativement stable, la couleur du sucre peut doubler ou même tripler en peu de temps. On a aussi suivi des sucres VHP et VLC stockes en vrac dans deux usines avec des systèmes de cristallisation différents (magma conventionnel et double) pendant deux saisons consécutives. Des sondes de tempéature et d’humidité relative ont été placées jusqu'à 15 m à l'intérieur des tas. Des échantillons ont été collectes régulièrement pour évaluer les effets des conditions de stockage sur la couleur, la pureté, la concentration de sucres invertis et d'autres paramètres. Il a été conclu que le sucre de haute qualité stocke mieux par rapport au sucre conventionnel. Toutefois, même le sucre VHP peut doubler sa couleur pendant le stockage à long terme. L’échantillonnage près de la surface du tas de sucre (jusqu'à 1,5 m à l'intérieur) n'est pas représentatif de la majeure partie de sucre. Il a été constaté que la température du sucre suit la tendance ambiante jusqu'à 3 m à l'intérieur du tas. Le sucre à 1,5 m de la surface qui n'était pas soumis à une hausse de température se conserve mieux que le sucre dans le coeur du tas. On ne sait pas quelles conditions déclenchent une augmentation de la couleur au stockage. Les changements de température du sucre brut au cours du stockage dans les entrepôts commerciaux indiquent que des réactions exothermiques se déroulent dans le cœur du tas ; cela donne une augmentation de la couleur et une réduction du pol. Les réactions ont lieu même lorsque la teneur initiale en eau dans le sucre et la température sont conformes aux exigences acceptées pour garantir la sécurité du stockage (facteur de sécurité < 0,25 et température inférieure à 30 °C). Un pH bas pour le sucre peut être une des raisons qui rend le sucre moins stable pendant le stockage. Le refroidissement du sucre avant ou pendant le stockage sera considéré dans le future.
ESTUDIOS DE ALMACENAMIENTO POR LARGO TIEMPO DE AZÚCAR CRUDO DE ALTA CALIDAD.

Por

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PALABRAS CLAVES: VHP (Azúcar de Alto Pol), Almacenamiento, VLC (Azúcar de Bajo Color).

Resumen

Los contratos actuales de compra de azúcar, no tienen suficiente justificación económica para incrementar la calidad del azúcar crudo, sin embargo la tendencia actual es la producción de azúcar crudo de mejor calidad. Pocos estudios se han llevado a cabo sobre el almacenamiento a granel de azúcar de alto pol (VHP) y azúcar de bajo color (VLC), especialmente cuando el período del almacenamiento está entre 9 y 10 meses. Monitoreos realizados a cargamentos comerciales de azúcar, indicaron que después de un relativo seguro periodo inicial de almacenamiento, el color del azúcar se puede duplicar o incluso triplicar en un corto tiempo. Grandes arrumes experimentales de azúcar grados VHP y VLC obtenidos a partir de dos esquemas de cristalización (convencional y doble magma) fueron monitoreados en dos ingenios azucareros durante dos zafra consecutivas. Medidores de humedad relativa y temperatura fueron colocados hasta 15 m al interior de las pilas. Muestras de azúcar fueron tomadas periódicamente para evaluar los efectos de las condiciones de almacenamiento sobre el color, la pureza, contenido de azúcares invertidos, y otros parámetros. Se concluyó que el azúcar de mejor calidad se almacena mejor que el azúcar convencional. Muestras de azúcar tomadas cerca de la superficie (hasta 1.5 m al interior de la pila) no son representativas del comportamiento del azúcar a granel. Se encontró que la temperatura del azúcar sigue la tendencia de la temperatura ambiente hasta una profundidad de 3 m al interior de la pila. Azúcar a 1.5 m de la superficie que no estuvo sujeta a incrementos de temperatura durante el almacenamiento se almacenó mejor que azúcar que estaba en el centro de la pila. No se identificaron las condiciones de almacenamiento que incrementan el color del azúcar. Los cambios en el perfil de temperatura del azúcar crudo durante el almacenamiento en bodegas comerciales, indican que algunas reacciones exotérmicas están ocurriendo en lo más profundo de la pila que ocasionan incrementos de color y reducción de pol. Estas reacciones toman lugar incluso cuando la humedad inicial y temperatura del azúcar cumplen con los requisitos aceptados para un almacenamiento seguro (valor de seguridad menor a 0.25 y temperatura menor de 30°C). Uno de los factores que hace menos estable el azúcar durante su almacenamiento es el pH bajo. Alternativas para enfriar el azúcar antes o durante el almacenamiento.
MODIFIED SINGLE SULFITATION PROCESS FOR PRODUCING BETTER QUALITY PLANTATION WHITE SUGAR

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Abstract

The presence of sulfur in sugar, apart from making it potentially harmful for human consumption, causes the sugar to deteriorate at a faster rate during storage. These issues and the steep rise in sulfur prices, albeit temporary, have brought to the fore the need to reduce the sulfur dosage used in the production of plantation white sugar (PWS). The process generally used in the production of PWS (in addition to juice sulfitation) is syrup sulfitation, which reduces sugar colour by a further 6–15%. However, this reduction in sugar colour is short-lived and it also reduces the pH of the syrup, with the result that subsequent manufacturing processes are carried out under acidic conditions. Because of this, there could be significant sugar losses from sucrose inversion. The use of suitable biocides for cane and mill sanitation has been shown to reduce the acidity of the mixed juice, as also the quantum of the high molecular weight polymeric compounds in the sugar and the molasses. In view of these observations, a new process (the VMK process) was developed to produce PWS without resorting to syrup sulfitation, namely, a single sulfitation process using a polymer together with appropriate biocides that reduce impurities and colour by about 12–15%. This process was tried in a full season of about 100 days in a 2500 tcd factory where 25000 t of sugar was produced with colour below 80 IU. Further improvement in sugar quality was also achieved with the help of an on-line colour monitoring unit, WG Colormet 1.0, as well as through tight control on chemical consumption, especially that of lime and sulfur. The quality of the sugar, which was consistently achieved, showed colour to be <55 IU, conductivity ash <0.015%, calcium <30 ppm, pol >99.85, and dextran and sulfur below detectable limits. The colour transfer index was found to be 130:1 from clear juice to final sugar, as against the reported index of 100:1 from A massecuite to sugar. Based on these findings, a patent has been filed for the VMK process for the production of good quality PWS.

Introduction

Sulfur dioxide (SO$_2$) is a toxic gas. When it is used during the manufacture of any food product, residual traces of sulfur remaining in such food product may be hazardous to human health. Hence the use of SO$_2$ is always restricted. The food industry does not permit or recommend the use of any sulfur compounds for food preservation.

In the sulfitation process, the use of the sulfur burner is difficult as it causes the toxic SO$_2$ to be released into the atmosphere, leading to serious environmental pollution because of this potent greenhouse gas. It can also create health problems for the workers handling the sulfur burners.

Although the sugar manufactured through syrup sulfitation has low colour and good ‘lustre’ initially, it loses both the colour and the ‘lustre’ within a few months. Depending on storage conditions, the colour can increase from 60 IU to 100 IU or even 120 IU within 6 to 10 months. There are several reasons for this deterioration, but one of the main reasons is sulfur. When first
applied, SO₂ bleaches the syrup, reduces the iron present in the juice and makes it colourless, resulting in a low colour sugar. However, this is only a temporary effect. The colour returns with time, as the remaining iron compounds oxidise into dark-coloured compounds. In addition, the sugar retains high sulfur content.

Sulfur dioxide is first used to treat the juice, which helps in the clarification process. Then it is again used in syrup treatment. The latter treatment is known to reduce the viscosity of the syrup / massecuite and improve molasses exhaustion. It also reduces the pH to pH 5.5 or less depending on how much SO₂ is used. Hence, the crystallisation process is carried out in an acidic environment; this favours sucrose inversion, which, in turn, affects sugar recovery. The quantum of sulfur in the sugar produced in good sugar factories is about 15 ppm (the highest permissible level), but it can be over 25 ppm in the sugar produced by others.

The treatment of the syrup with SO₂ is known also to reduce sugar colour by just 6–15% (Keskar, 2009, pers. comm.; Londhe, 2009, pers. comm.). However, significant amounts of sulfur end up in the molasses which may be used for producing alcohol by yeast fermentation. Sulfur affects the fermentation of the molasses by inhibiting the growth of the yeast. Moreover, traces of the sulfur that get into the alcohol make it unsuitable for use as a fuel supplement, as also for use in the liquor and pharmaceutical industries, unless further refinements are carried out to remove these impurities.

Thus the use of SO₂ in syrup does not provide any significant benefit. Further, whatever benefit does result lasts only for a short period of time. This realisation prompted the development of an alternative technology that would avoid at least syrup sulfitation and help in producing good quality sugar.

The use of appropriate biocides in proper doses is known to limit the microbial degradation of mixed juice and hence limit any reduction in the acidity of the primary and mixed juice and prevent the formation of degradation products like polysaccharides (Kulkarni, 2004). Further, the need for additional lime is prevented and the level of residual calcium as soluble organic calcium salts in the clear juice is not increased. Similarly, there is some reduction in the rise in the colour of juices (Kulkarni and Warne, 2004).

Any reduction in polysaccharide content can play a significant role in molasses exhaustion, especially when syrup sulfitation is avoided. The use of appropriate biocides in the process can control the rise in this polysaccharide content; however, polysaccharides already present in the sugarcane and formed during the cut-to-crush delay will obviously get concentrated. The use of a mixture of crystal mobilisers, crystal developers and viscosity reducers can help to improve the pan output, as well as in better exhaustion. Such a formulation is also known to reduce sugar colour by about 12% (Kulkarni and Pallod, 2005). Thus, even when syrup sulfitation is avoided, its benefits can be more than matched by using appropriate biocides.

New single sulfitation process—VMK process

A new process has been developed, which requires only a slight modification to the existing process. It seeks to prevent the entry of impurities into the process. This is done by using appropriate chemicals in proper doses at the right stages of the process. Some of the currently used chemicals are replaced in the new process with more appropriate chemicals while others are new as identified in Table 1. Apart from the changes in the chemicals, the only modification needed in the process is the isolation and shutting down of the sulfur burner for the syrup.

Chemicals used in the VMK Process

Polmax Supreme is used for cane sanitation by spraying onto prepared cane at 2–5 ppm before the cane enters the fiberisor hammer. It consists of various salts of methyl and ethyl dithiocarbamates, organo-sulfur based activator and penetrating agents and has an active ingredient concentration of 40%. Up to 90% of the microbes are killed in just one minute of the spraying if Polmax Supreme is sprayed onto the cane at 10 ppm.
Polmax ESR is used for mill sanitation. It is added continuously at 10 ppm with the application split between all mills after the 2nd mill. It is a chemical formulation of various salts of methyl and ethyl dithio-carbamates and has an active ingredient concentration of 40%. At a dosage of 10 ppm, 90% of the microbes in the cane juice are killed in 10 minutes.

Table 1—Chemicals used for the VMK Process and cost comparison with normal process for one million tonnes of cane.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normal process</th>
<th>VMK process</th>
<th>Cost implication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane sanitation</td>
<td>Not used</td>
<td>Polmax Supreme @ 5 ppm</td>
<td>+USD30 000*</td>
</tr>
<tr>
<td>Mill sanitation</td>
<td>About USD20 000 Carbamate @ 10 ppm</td>
<td>Polmax ESR @ 10 ppm, USD29 000</td>
<td>+USD9000*</td>
</tr>
<tr>
<td>Lime</td>
<td>Used based on experience</td>
<td>Dose specified as per results</td>
<td>Could be reduced</td>
</tr>
<tr>
<td>Phosphoric acid</td>
<td>Used arbitrarily</td>
<td>Used judiciously (Not used)</td>
<td>Can be reduced</td>
</tr>
<tr>
<td>Flocculating agent</td>
<td>Magnafloc LT27 @ 1–2 ppm</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.07% or more (700 t)</td>
<td>0.03% saving about 300 t</td>
<td>– USD45 000**</td>
</tr>
<tr>
<td>Special agents</td>
<td>Colour precipitant, USD7 /kg, @ 10 ppm</td>
<td>Sucolor @ 10 ppm, US$ 7 /kg</td>
<td>+ USD70 000* May not change</td>
</tr>
<tr>
<td>Viscosity reducer</td>
<td>Unspecified surfactant 2–5 ppm</td>
<td>New formulation 2–5 ppm</td>
<td>+ USD20 000*</td>
</tr>
<tr>
<td>Colour coagulant</td>
<td>Used to improve colour</td>
<td>Not used</td>
<td>?</td>
</tr>
</tbody>
</table>

* Prices are calculated at maximum use of chemicals for the VMK Process, actual use of chemicals could be less depending on factory conditions.
** Saving is more as sulfur consumption is less than 0.017%

Sucolor is used as an impurity-removing agent. It is added continuously at 10 ppm in the clear juice receiving tank. It is a special polymer of coco-di methyl amine, which reduces the affinity of various impurities to attach themselves to the sucrose crystal lattice during growth. Thus the colour transfer index is improved to produce lower coloured sugar.

Viscosity reducer is used to improve crystallisation and improve crystal washing efficiency. It is a formulation of various glycols, oleates, acetates with surfactants. It is added continuously at 2–5 ppm to the syrup.

Thus there would be some rise in the cost of process chemicals used for the VMK process as compared to the normal double sulfitation process for factories that do not use special agents like colour coagulants and/or colour precipitants. However, considering the benefits of lower inversion losses of sucrose, the VMK process offers economical advantages over the normal process.

Experiment 1
Initially, during the season 2006–2007, trials were successfully carried out for 15 days, which were repeated for 45 days, in a 3500 tcd factory, the Kisan Veer Statra S.S.K. Ltd., at Bhuinj, near Satara.

There was noticeable improvement in the process with respect to steam consumption, quality of bold grain sugar and bagasse savings. The viscosity reduction assisted to reduce the boiling time of A strikes by 10 minutes and B strikes by 20–30 minutes. About 135 000 bags of sugar were produced without syrup sulfitation.

This sugar was sent for analysis to Maarc Labs, Pune (an ISO 17025 lab accredited by NABL). Their report clearly states that the quality of the sugar produced by this process was very good. The SO₂ content and dextran content were below detectable levels and it had a microbial count of less than 120 cfu per 10 g. The conductivity was only 0.014%, and the moisture and calcium levels were lower. This substantial reduction in most of the impurities as compared to those found in the normal PWS has also improved the sucrose content to 99.85% pol.
Sugar of such quality has been produced for the first time in India without the use of any additional equipment or any modification to the process for clarifying the juice and syrup. It is also noticed that the pH of the sugar was more than 6.6. Table 2 gives the requirements for PWS as per IS specifications, EU II specifications and the results obtained by using the VMK process.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>IS 5982–2003</th>
<th>Codex 2004</th>
<th>VMK process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum moisture, %</td>
<td>0.10</td>
<td>0.06</td>
<td>0.0156</td>
</tr>
<tr>
<td>Minimum sucrose, %</td>
<td>99.5</td>
<td>99.7</td>
<td>99.87</td>
</tr>
<tr>
<td>Maximum reducing sugars, %</td>
<td>0.10</td>
<td>0.04</td>
<td>0.01</td>
</tr>
<tr>
<td>Maximum colour, IU</td>
<td>150</td>
<td>45</td>
<td>70</td>
</tr>
<tr>
<td>Maximum conductivity ash, %</td>
<td>0.1</td>
<td>0.027</td>
<td>0.0146</td>
</tr>
<tr>
<td>Maximum sulfur dioxide, mg/kg</td>
<td>70</td>
<td>15</td>
<td>&gt;5</td>
</tr>
<tr>
<td>Maximum lead, ppm</td>
<td>5.0</td>
<td>1.0</td>
<td>ND</td>
</tr>
</tbody>
</table>

**Experiment 2**

The same factory, Kisanveer Satara SSK Ltd., produced raw sugar during the season 2007-2008 and similar trials were conducted for a week to produce raw sugar without the use of sulfur. The sugar looked good and also had ‘lustre’, with a colour of 170 IU. Although the colour was higher than the IS specifications for PWS, the raw sugar looked better than one year old PWS from some factories. The raw sugar was sent for analysis at Savola Sugars, KSA, which revealed that it was better than the best raw sugar developed in Brazil (Table 3), especially with respect to conductivity ash and some other impurities. This sugar is now called pre-refined (PR) sugar. It is best suited as raw material for sugar refineries for producing refined sugar, with minimal difficulties and at low cost.

<table>
<thead>
<tr>
<th>VHP</th>
<th>VVHP</th>
<th>QHP</th>
<th>EHQ</th>
<th>PR sugar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pol</td>
<td>99.2</td>
<td>99.6</td>
<td>99.6</td>
<td>99.7</td>
</tr>
<tr>
<td>Colour, IU</td>
<td>1500</td>
<td>450</td>
<td>700</td>
<td>350</td>
</tr>
<tr>
<td>Ash, %</td>
<td>0.20</td>
<td>0.15</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Invert, %</td>
<td>0.25</td>
<td>0.15</td>
<td>0.15</td>
<td>0.1</td>
</tr>
<tr>
<td>Starch, mg/L</td>
<td>250</td>
<td>110</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Insoluble solids, mg/L</td>
<td>250</td>
<td>150</td>
<td>100</td>
<td>50</td>
</tr>
</tbody>
</table>

**Experiment 3**

The VMK process with single sulfitation was also tested at a 2500 tcd private factory, Cane Agro Energy Ltd., Dongari near Karad for the entire 2007–2008 season. A WG Colormet 1.0 instrument was used to display online the colour level of the clear juice every 10 seconds. This helped in the optimisation of chemicals used for the clarification.

The optimisation of the process resulted in production of sugar with colour less than 60 IU for about a month. Sometimes, a colour of 50 IU was also recorded. During this optimisation of the clarifier it was observed that, depending upon cane quality; the lime quantity could be reduced and therefore sulfur quantity in achieving better colour removal. Hot liming was used with simultaneous sulfitation, whereby the quantity of lime was reduced, with a concomitant reduction in sulfur, to maintain pH 6.9 in the clear juice. This adjustment was based on the observation of clear juice colour on the WG Colormet 1.0.
These observations were then used to reduce the lime quantity and thus sulfur quantity, in order to maintain the colour of the clear juice at around 8000 IU. The lime and sulfur quantities used were the lowest for the final three weeks of the season (days 65 to 80 in Figures 1 and 2).

The colour of the clear juice was around 7500–8500 IU and the sugar colour was often below 60 IU, especially in the final three weeks.

Figure 1 shows that the colour transfer index increased from a typical 100:1 to more than 130:1 during the last three weeks of the season. This could be due to the better clarification, as well as the better process control assisted by the online monitoring of the clear juice colour. This resulted in the reduction in sulfur consumption to less than 0.017% on cane, yet sugar with less than 60 IU colour was produced.

Figure 2 shows the daily average sugar colour for the season. Figure 3 shows the daily average sugar colour (×100) and clear juice colour during experiment 3.
Conclusion

Good quality sugar can be produced by avoiding syrup sulfitation without entailing any additional capital expenditure on equipment etc or any alterations or modifications in the process. Sulfur consumption can be reduced still further by using the WG Colormet 1.0 to monitor online the colour of the clear juice. Depending on the cane quality, sulfur consumption on cane can be reduced to less than 0.02%. In short, the VMK process can be adopted for producing both PWS and raw sugar. For PWS, the VMK process uses single sulfitation while, for raw sugar, it dispenses with the use of sulfur altogether.

The quality of the PWS as well as the raw sugar produced by the VMK Process is superior to that of the normal PWS and raw sugar respectively. The lower sulfur consumption and, consequently, the lower residual sulfur content in the sugar means that the keeping quality of the sugar is superior to the PWS sugar.

Acknowledgements

The author wishes to acknowledge the support given by Mr Madan Bhosale, MLA, Chairman, Kisanveer Satara SSK Ltd., without which the experiment could not have initiated and by Mr Chandrashekhar Ogale, MD, Cane Agro Energy Ltd., for giving permission to use the process at his factory for trials during a full season. Dr Vishwas Udpikar, Dr Ramesh Natu and Dr Mrs. Dhamankar are thanked for their support and work on WG Colormet 1.0.

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SULFITAGE SIMPLE MODIFIÉ POUR LA PRODUCTION DE SUCRE BLANC PLANTATION AVEC UNE MEILLEURE QUALITÉ

Par

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MOTS-CLES: Sulfitage, Soufre, Sucre Blanc de Plantation, Impuretés, Processus VMK.

Résumé

La présence du soufre dans le sucre le rend potentiellement nuisible à la consommation humaine et entraîne le sucre à se détériorer plus rapidement au cours du stockage. Ces questions et la forte hausse des prix du soufre, quoique temporaire, demandent la réduction de la dose de soufre utilisée pour la production de sucre blanc plantation (PWS). Le processus généralement utilisé dans la production du PWS (en plus du sulfitage du jus) est le sulfitage du sirop, ce qui augmente la décoloration du sucre par 6–15%. Toutefois, cette réduction en couleur de sucre est de courte durée; elle réduit également le pH du sirop, de sorte que les procédés de fabrications ultérieures sont effectués en milieu acide. De ce fait, il pourrait y avoir des pertes de sucre significatives grâce à l'inversion du saccharose. L'utilisation de biocides appropriés pour l'assainissement des cannes et des moulins réduit l'acidité du jus, comme aussi le quantum des composés polymères de haut poids moléculaire dans le sucre et la mélasse. Compte tenu de ces observations, un nouveau processus (le processus VMK) a été développé afin de produire le PWS sans avoir recours au sulfitage du sirop, à savoir, un processus de sulfitage simple à l'aide d'un polymère avec biocides appropriés qui réduisent les impuretés et les couleurs d'environ 12 à 15%. Ce processus a été utilisé pendant une saison complète d'environ 100 jours dans une usine broyant 2500 tonnes de canne par jour; on a produit 25 000 tonnes de sucre avec une couleur inférieure à 80 UI. On a également obtenu une amélioration de la qualité du sucre à l'aide d'un appareil WG Colormet 1.0 surveillant la couleur en ligne, ainsi que par le contrôle strict sur la consommation de produits chimiques, en particulier celui de la chaux et du soufre. La qualité du sucre, qui a été constamment obtenue, a montré une couleur à 55 UI, une conductivité (basée sur les cendres) de 0.015 %, un calcium de 30 ppm, un poI > 99.85; le dextran et le soufre n’ont pas été détectés. L’indice de transfert de couleur a été 130:1 à partir du jus clair au sucre final, par rapport à l'index signalé de 100:1 d'une massecuite au sucre. Selon ces conclusions, un brevet a été déposé pour le processus de VMK pour la production de PWS d’une bonne qualité.
PROCESO MODIFICADO DE SULFITACIÓN SIMPLE PARA PRODUCIR AZÚCAR BLANCO DE MEJOR CALIDAD

Por

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PALABRAS CLAVE: Sulfitación Simple, Bajo Azufre, Azúcar Blanco, Impurezas Proceso VMK.

Resumen

LA PRESENCIA de azufre en el azúcar, además de hacerlo potencialmente nocivo para consumo humano, causa que el azúcar se deteriore a una tasa más alta durante el almacenamiento. Estos aspectos junto con el incremento en los precios del azufre, han resaltado la necesidad de reducir las dosis de azufre usadas en la producción de azúcar blanco. El proceso generalmente seguido, además de la sulfitación de jugo, es la sulfitación de meladura, la cual reduce el color un 6–15% adicional. Sin embargo, esta reducción es de corta vida y también reduce el pH de la meladura con el inconveniente que las etapas posteriores de proceso se realizan bajo condiciones ácidas. Debido a esto pueden existir pérdidas importantes por inversión de sacarosa. El uso de biocidas adecuados y sanitización de molinos han mostrado reducciones en la acidez del jugo diluido así como de la cantidad de compuestos poliméricos de alto peso molecular en azúcar y mieles. Un nuevo proceso (proceso VMK) fue desarrollado para producir azúcar blanco sin recurrir a la sulfitación de meladura, es decir, un proceso de una sola etapa, usando un polímero junto con biocidas apropiados que reducen impurezas y color en cerca de 12–15%. Este proceso fue ensayado en una zafra de cerca de 100 días en una fábrica de 2500 tcd, donde se produjeron 25 000 t de azúcar con color por debajo de 80 IU. Un mejoramiento adicional de la calidad del azúcar se obtuvo con la ayuda de una unidad de monitoreo continuo de color, WG Colormet 1.0, así como con cuidadoso control del consumo de químicos, especialmente de cal y azufre. La calidad del azúcar, lograda en forma sostenida, <55 IU, conductividad de cenizas <0.015%, calcio <30 ppm, pol >99.85, y dextranas y azufre por debajo de los límites detectables. El índice de transferencia de color se encontró como 130:1 desde jugo claro hasta azúcar final, frente al índice reportado de 100:1 desde masa A hasta azúcar. Con base en estos hallazgos se ha solicitado patente para el proceso VMK para la producción de azúcar blanco de buena calidad.
IMPLEMENTATION PLANS FOR SUPERVISORY CONTROL OF PAN STAGE OPERATIONS

By

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Abstract

PAN STAGE operations have a major influence on the quality of shipment sugar production, the processing efficiency of the centrifugal and dryer stations, the sugar recovery from final molasses and the steam consumption of raw sugar factories. As well, for many factories, the production capacity of the pan stage is often the rate limiting station of the factory. Several Australian factories now operate with only one pan stage operator and a management tool such as a smart supervisory control system (SSCS) would assist the operator in making better decisions for managing the stage. The SSCS integrates the projected boil-on rates for syrup and molasses to each pan on the stage with the forecast production of syrup based on cane receival data and molasses from the centrifugals. By using the phase of each pan into an operational model the levels of syrup, A molasses and B molasses in the respective stock tanks are forecast and the information used to forewarn of potential problems or inefficiencies if current operating strategies are maintained. A hybrid fuzzy logic based expert system is employed to advise corrective procedures. While the system is not yet adopted commercially each phase of the development plan has been undertaken. Forecast tank levels have been found to compare favourably with actual tank levels. The SSCS should result in improved use of the installed equipment on the pan stage to achieve increased sugar recovery, improved sugar quality and reduced steam consumption while fulfilling the production rate requirements. One of the important benefits of the control system should be reduced variability in the steam consumption on the pan stage, leading to improved steam economy for the factory.

Introduction

Australian sugar factories face two major costs, viz. high unit labour costs and high capital costs for equipment. As a consequence, each factory employs only a few operators/supervisors and capital items are generally large (and few in number) in order to capture the benefits of economies of scale. For example, for the pan stage, several factories have only one operator to manage the whole stage (typically 8 pans) and batch pans of 200 t dropping capacity are common through the industry.

Most Australian factories employ only one supervisor to oversee all operations from the cane weighbridge, milling and boiler stations, through to the sugar bin and outloading. The number of operators on shift for the whole plant is about 11.

For several years, the benefit of a supervisory/advisory support tool for pan stage operations in sugar factories has been recognised (Frew and Wright, 1977; Merensky, 1985; Watson, 1989; Verwater-Lukszo et al., 2003), but it appears no system is currently operating to the extent considered necessary for strongly beneficial results.
Supervisors and operators currently rely on their knowledge and experience of the process, and the operational plan nominated by the production manager, to manage the operations of the shift. However, the complexity of the task in operating the pan and fugal stations in an optimal way has increased and at the same time the financial implications of those outcomes have increased. To achieve a truly optimal result, management decisions for the pan and centrifugal stations must be undertaken in relatively short time frames e.g. during each hour, and compliance with a rigid operational plan set by the production manager may not be appropriate. Ideally the production manager will set the production objectives for the shift and the supervisor/operators will make real time optimal decisions to meet those objectives.

A smart supervisory control system (SSCS) was developed as a management tool to assist the operator in making better decisions for managing the stage.

**Pan stage operations in Australian sugar factories**

Figure 1 shows the typical flowscheme adopted by Australian mills to produce raw sugar with polarisation between 98 and 99.4, depending on the customer requirements. The syrup from the evaporators is usually at 88 to 92.5 purity. The flowscheme incorporates three grades of massecuite (A, B and C) with the mixture of the A and B sugar production being combined and dried to produce the shipment sugar of mean size 0.8 to 1.0 mm. The C sugar provides the crystal seed material to produce a high grade seed (after boiling on syrup) for the A and B massecuite production. The flowscheme incorporates a complex combination of feedforward (e.g. some syrup fed onto the B strikes; A molasses (or syrup) onto the grainings for the C strikes) and feedback (e.g. A molasses onto the A strikes). Both batch and continuous pans are used and batch and continuous centrifugals are used for processing the A and B massecuites. Only continuous centrifugals are used for processing the C massecuite.

The high interdependency of operations on the pan stage and the centrifugal station requires that optimal supervision of the two stations is considered collectively and not in isolation. The management of the centrifugals/dryer station is undertaken by a different operator from the pan stage.

**Operational objectives for managing the pan and centrifugal stations**

The operational objectives for the pan and centrifugal stations are a combination of the following:
• Throughput rate. The A, B and C massecuite production rates per tonne of cane crushed changes as the sucrose and soluble impurity content of the cane supply changes. A farmer’s supply of cane to the factory (known as a rake of cane) may vary from four minutes to 30 minutes of cane crushed by the milling train and the composition will vary from rake to rake and to a lesser extent within the rake. In addition to this variation is the more significant variation in the cane composition through the season. The cane supply has a lower sucrose content and higher soluble impurity content in the early and late periods of the crushing season and a higher sucrose content and lower soluble impurity content in the mid-season period. The typical effect of the seasonal change in cane composition on the A, B and C massecuite production rates is shown in Table 1 (Broadfoot and Pennisi, 2001).

<table>
<thead>
<tr>
<th>Massecuite type</th>
<th>Massecuite % cane</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Early season</td>
</tr>
<tr>
<td>A</td>
<td>12.8</td>
</tr>
<tr>
<td>B</td>
<td>11.5</td>
</tr>
<tr>
<td>C</td>
<td>6.6</td>
</tr>
</tbody>
</table>

• Sugar quality. The main sugar quality parameter that is influenced directly by pan stage operations is the mean size (and uniformity) of the A and B sugars. The centrifugal station impacts directly on the polarisation of the shipment sugar. Variations in the wash water addition in the A and B fugals to meet the pol specification directly affect the extent of sugar dissolution during fugalling and consequently affect the A and B massecuite production quantities. Sugar of premium quality receives a bonus payment so revenue for sugar production is directly affected by the quality.

• Sugar recovery. Improved exhaustion of the C massecuites, yielding final molasses of lower purity directly results in increased sugar production from the sucrose in the syrup supply to the pan stage. For the three-massecuite boiling scheme used in Australian factories, a critical operational target for the pan stage is to ensure that the B molasses is at an appropriately low purity, otherwise the production of a higher purity C massecuite will result in increased sucrose loss to final molasses. Reduced sugar recovery occurs when the soluble impurity content of the cane supply is high, resulting in increased production of B and C massecuites, and final molasses.

• Steam/vapour consumption for the pan stage. As a consequence of the large batch pans that are used in Australian factories, the steam/vapour consumption on the pan stage commonly varies through the pan stage cycle by +/-25% about the mean. These fluctuations impact negatively on the steady operation of the evaporators (where bleed vapour is used on the pan stage) or increase the make up of high pressure steam to the exhaust steam mains and venting of steam to atmosphere. The fluctuations in steam/vapour consumption on the pan stage usually result in inefficient use of steam and reduced revenue from attached cogeneration plants. Smoothing of the steam/vapour usage on the pan stage is highly beneficial.

The optimal operational plan set by the production manager for a shift (or perhaps 24 h period) is a weighted consideration of all four criteria with the weighting (importance) placed on the individual criterion varying in the short and long term. For example, during mid season when the
sucrose content in the cane supply is at its peak, stronger emphasis will be given to throughput rate; if the cane crop is reduced, greater emphasis will be placed on sucrose recovery and quality; if there is a mechanical breakdown in a section of plant and crushing rate is reduced, greater emphasis will be given to sugar recovery, sugar quality and perhaps steam consumption.

It is possible to produce a single weighted objective function for the pan and fugal stations for the shift and use the supervisory/advisory control system to manage the operations to best meet the requirements of that objective function. The supervisory system uses real time data and input from the supervisor and operators to take into account the operational circumstances for the shift. For example, if a particular pan experiences a vacuum leak and its boil-on rate is affected, then this needs to be included in the supervisory plan.

**Overview of the framework for the smart supervisory control system**

Figure 2(a) shows the information transfer between the operator, the pan stage control system and the pan stage plant that is currently used in most Australian factories. The smart supervisory control scheme (SSCS) works in tandem with the pan stage operator and the current pan stage control systems to make projections of performance against the nominated objective and to provide advice. Figure 2(b) shows the information transfer for the pan stage incorporating the SSCS.

![Diagram showing information flow between operator, pan stage control system, and pan stage plant with current and smart supervisory control systems](image-url)

The SSCS takes operator input along with information from the existing sugar mill control system and factory databases (such as cane receipt information) and provides recommendations and expert advice. The operators use the advice/recommendations from the SSCS to influence their management of the pan stage and fugal station operations e.g. through the values they input to the pan stage and fugal station control systems, allocation of pans to A or B massecuite boiling etc.
There are four primary outputs provided by the SSCS, viz.
1. Pan duties management;
2. Pan control strategies;
3. Pan scheduling management; and
4. Stock tank management.

In addition the SSCS provides support information to the operators in two categories, viz.
1. Prediction of future pan stage operating conditions; and
2. Explanatory and justification capabilities.

The SSCS is a hybrid fuzzy logic based expert system design incorporating rule based decision making, explanatory capabilities and process models (Dodd et al., 2005a; Dodd et al., 2009). The knowledge base is composed of human expert knowledge coupled with mathematical models simulating the pan stage and centrifugal station processes.

This arrangement maintains significant human interaction with the SSCS as part of the process, which is considered to be highly desirable.

Framework of the supervisory control system

The framework of the SSCS is based upon conventional expert systems (Leung and Wong, 1990; Gisolfi and Balzano, 1993) and conventional If-Then fuzzy rule based systems design (Goel et al., 1995; Berkan and Trubatch, 1997). Dodd (2009) provides a detailed description of the framework and core operations of the SSCS.

As depicted in Figure 3 the SSCS incorporates several modules performing multiple tasks. This modular structure aids in maintenance, upgradeability and flexibility. A brief description of each of the modules follows.

Input module

The input module draws real time information directly from the sugar mill control system through relevant databases including information on cane receival (rate, juice analyses), juice processing station, laboratory analyses (syrup purity), the pan stage and centrifugal station.

Pan stage operators provide information such as equipment performance ratings, operational problems, plus characteristics of the syrup, molasses and sugar process streams.

Editor module

The editor module provides the capabilities to modify the functional parameters for the process model input parameters and output data to match the local operating conditions. As well, this module can assign or modify the explanations tagged to each of the rules.

Data module

The data module contains several databases for information storage including the fuzzy If-Then rule knowledge base, the parameters specific to the pan stage models, databases storing text based information for presentation to the operators, a blackboard system for storing the predicted values of the process variables (from the process models) and from the rule based decision making block, information from the sugar mill control system (including information from cane receival, the juice processing station, laboratory, pan stage and the centrifugal station).

Input data from the operators on the pan and centrifugal stations are also captured in this module. The information flows in Figure 3 show the important role of the blackboard system, as the working memory for results from the pan stage process models, and the rule based decision making block. Output data are obtained from the blackboard data system.
System module

The system module carries out data processing of the two major sources of input information and transforms these to six system outputs. The system module is the most complex and essentially comprises the majority of the system software operations. The system module contains three subsystems as shown in Figure 3 viz.:

- Process models of the pan stage;
- Rule based decision module adjusting process models for local conditions; and
- Explanatory communications.

In total six process models are used for the predictions of pan stage and fugal station conditions and these are described in Table 2.

Fig. 3—Framework of the SSCS.
Table 2—Descriptions of the models used in the SSCS.

<table>
<thead>
<tr>
<th>Model name</th>
<th>Model description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pan and fugal phase determination models</td>
<td>Determines the current status and phase within the pan stage schedule for each vacuum pan and the status of the centrifugal station. For the pans, a simple classification procedure based upon steam usage, level and change in level as presented by Frew and Wright (1976) is used. Receiver levels and change in receiver levels allow fugal station status to be inferred. Once this determination is made, this model is coupled with the pan stage schedule and the other process models for prediction of future pan stage operating conditions.</td>
</tr>
<tr>
<td>Syrup prediction model</td>
<td>Determines the future flow of syrup to the pan stage based on cane receive data at the weighbridge and laboratory. The prediction of the quantities of sucrose and impurities in the syrup stream allows a forward forecasting of the stocks of syrup. The forward predictions of syrup rate and composition are key inputs to predicting the massecuite production loadings.</td>
</tr>
<tr>
<td>A, B, C massecuite model</td>
<td>Calculates the average production rates of A, B and C massecuites, C sugar remelt, molasses and sugar streams given the syrup purity and flow rate to the pan stage. Crystal sizing determinations assist in calculating the necessary quantities of C sugar needed for the A and B pans to ensure final product sugar is of the required size. Typical parameters for crystal content, sugar size, coefficient of size variation and purity rise at the fugals are assumed in this model.</td>
</tr>
<tr>
<td>Empirical pan models</td>
<td>The rate at which each pan takes feed material (syrup, A molasses or B molasses) during the different phases of the pan's operation is determined by experimentation and modelling. This boil-on rate for feed materials is a function of the massecuite level and phase of the pan, steam rate, head space pressure (vacuum), brix and purity of the feed syrup/molasses.</td>
</tr>
<tr>
<td>Stock tank prediction models</td>
<td>By using the empirical pan models, the boil-on rates for each feed stream at the different stages of the pan stage schedule can be determined by summing the syrup, A molasses and B molasses feed rates for all the pans at that point in the schedule. Given the expected syrup production rate and C sugar remelt production rate, the predicted tank levels can be determined for the syrup tank for a series of intervals. Similarly, the predicted tank levels for the A and B molasses can be calculated from the production rates of the molasses at the centrifugal station and the sum of the consumption rates on the individual pans at the specific point in the pan stage schedule.</td>
</tr>
</tbody>
</table>
| Schedule optimisation model                          | Manages the schedule e.g. determines when pans should start and complete strikes to avoid pan idling, while minimising and smoothing steam usage on the overall pan stage and adhering to sugar production productivity, recovery and quality requirements. This model optimises the objective function. The information from this model is used in conjunction with information gathered through the input module, the rule based decision making process and from the other process models to provide information on:  
  • Recommended steam rates for the specific phases of the individual vacuum pans;  
  • Choice of A/B massecuite duties for the ‘swing’ vacuum pans;  
  • Forecasting of stock tank levels and future disturbances e.g. tank overflow;  
  • Footing quantities to the vacuum pans; and  
  • Scheduling when pans should start and complete strikes. |

The SSCS uses default parameters for the process models from the pre-defined knowledge base. However, to customise the SSCS for the current or defined operating circumstances, the fuzzy logic rule block uses the input data from the operator/supervisor to pre-process the pan stage models input parameters and, likewise, to post-process the output results from the models to align with the current and defined operating conditions. The post-processing results take precedence over the pan stage model output values and these are stored on the blackboard system for subsequent use by the models.
Examples of pre-processing and post-processing adjustments to match local operating conditions are:

- If cane is fresh and A massecuite purity is greater than 88 and the target pol of A sugar at the fugals is between 99.0 and 99.1, then A fugal purity rise = 1.75 units;
- If a vacuum leak exists on a particular pan, then set the boil-on rate characteristic for the pan to 0.92. It would be 1.0 at typical vacuum;

For a particular factory, the refinements that are undertaken through the fuzzy logic rule block customise the SSCS to suit the specific equipment and operational circumstances for the factory.

**Output and support modules**

The four control strategy recommendations are passed from the blackboard data system to the output module. The supporting results, including justifications for the presented advice and predictions for future pan stage operations, are provided in the support module.

**Application of the SSCS**

While the SSCS system is not yet adopted commercially, each phase of the development plan has been undertaken. Dodd (2009) provides the detailed specification for the framework, the incorporation of the process models, the software for implementing the fuzzy logic block and the procedures for communicating data among the modules.

Factory data were obtained from the databases at Racecourse Mill to assess the suitability of the prediction models for use in the SSCS. Information on these assessments is provided in the sections to follow.

**Syrup rate prediction**

Dodd et al. (2005a) outlined the procedure using cane receival data (cane rate and pol % cane) to forward predict the quantity of sucrose in syrup to the pan stage from cane and subsequently, using laboratory analysis of the purity of syrup, to determine the quantity of impurities in syrup. The model uses rolling average error corrections to accommodate the analytical errors in syrup and cane analyses and the variations in impurity/sucrose losses between cane receival and the pan stage (i.e. to allow for losses in mud, bagasse, degradation and analytical anomalies). Dodd et al. (2005a) demonstrated a high level of agreement of the predictions with syrup rates measured by magnetic flowmeters for a whole season at two factories.

**Empirical pan models**

For each phase in each pan at Racecourse Mill, the syrup or molasses boil-on rate was determined from the change in level in the pan (as measured by a differential pressure transducer), the brix of the feed material and the brix of massecuite at the start and finish of the phase (Dodd et al., 2005b).

The measured boil-on rate was assigned to the current operating status for the pan using the classification procedure based on steam rate, level and change in level according to the procedure of Frew and Wright (1976). An iterative computer simulation for a batch pan was used to determine the change in syrup or molasses boil-on rate with change in steam rate to the pan.

Thus, within practical operational constraints, the steam rate during a phase of a pan, and collectively for all pans, can be adjusted to provide an improved outcome for the total pan cycle by avoiding idling time, increasing productivity, smoothing steam demand etc.

**A, B and C massecuite model**

This model develops steady state mass balances for all streams (massecuite, sugar, molasses, remelt, magma) on the pan stage and is well tested against factory data (Broadfoot and Pennisi, 2001).
Stock tank models

These models determine the stock tank levels for the syrup, A molasses and B molasses by utilising the above models plus the pan and fugal phase determination model and the schedule optimisation model. Figure 4 shows a comparison between the actual quantity of syrup in the stock tank and the predicted quantity for an 8 h period at Racecourse Mill. Similarly, Figure 5 shows the comparison of the predicted and actual levels for A molasses over the same 8 h period.

![Figure 4](image1.png)

**Fig. 4—Comparison of forward prediction of syrup stock tank levels with actual data.**

![Figure 5](image2.png)

**Fig. 1—Comparison of forward prediction of A molasses stock tank levels with actual data.**

The data provided in Figures 4 and 5 are snap-shot data from an on-going forecast. In practice, when the SSCS is implemented, the projection for a specific time period will use the actual tank level as the starting position, resulting in closer alignment.

Conclusions

The SSCS is a hybrid fuzzy logic based expert system incorporating rule based decision making, explanatory capabilities and industrial process models of the pan stage and fugal stations. While the SSCS has not yet been commercially adopted, all components have been developed and its forecasting capability appears to be satisfactory.

The next step is to implement the system into a factory. The objective of the SSCS is to provide advice to supervisors and operators so that early decisions, such as changes to steam rates or allocation of pans to different duties, result in improved outcomes with respect to avoiding production rate difficulties, and maintaining good operational performance with respect to sugar quality, sugar recovery and minimisation of steam consumption on the pan stage.
Acknowledgments

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REFERENCES


PLANS POUR L’INTRODUCTION D’UN SYSTÈME DE CONTROL POUR CONDUIRE LES CUITES

Par

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MOTS CLEFS: Control, Logique Fuzzy, Logiciels, Models pour les Cuites.

Résumé

Les opérations aux cuites ont une influence majeure sur la qualité du sucre, l'efficacité des centrifuges et du sécheur, le recouvrement du sucre dans la mélasse finale et sur la consommation de vapeur des usines de sucre roux. Pour beaucoup d'usines, la production est limitée par la capacité de la station des cuites. Plusieurs usines australiennes fonctionnent maintenant avec un seul opérateur aux cuites; un outil de gestion, comme un système de contrôle intelligent (SSCS), pourrait aider l'opérateur à prendre de meilleures décisions. Le SSCS intègre les taux d'ébullition projetés pour sirop et mélasses à la production de sirop basée sur le tonnage de canne et à la production de mélasses des centrifuges. En utilisant la phase de chaque cuite dans un modèle opérationnel, on prédit les niveaux de sirop, de mélasse-A et de mélasse-B dans les réservoirs; ces informations évitent d'éventuels problèmes. Un logiciel est employé pour donner des procédures correctives. Quoique le système ne soit pas encore adopté commercialement, chaque phase du plan de développement a été entreprise; les niveaux calculés dans les réservoirs se comparent favorablement avec les niveaux mesures. Le SSCS doit aboutir à une meilleure utilisation de l'équipement installé, il devrait aussi donner une augmentation du sucre produit, une meilleure qualité de sucre et une consommation de vapeur réduite. L'un des avantages importants du système de contrôle est une réduction de la variabilité de la consommation de vapeur, et donc une économie de vapeur pour l'usine.
PLANES DE IMPLEMENTACIÓN PARA UN CONTROL SUPERVISORIO DE LAS OPERACIONES EN LA ESTACIÓN DE TACHOS

Por

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PALABRAS CLAVE: Control Supervisorio, Lógica Fuzzy, Sistemas Expertos, Modelos De Cocimiento.

Resumen

LAS OPERACIONES en tachos tienen una influencia clave en la calidad del azúcar final, la eficiencia de las estaciones de centrífugas y secado, las pérdidas en miel final y el consumo de vapor de las fábricas de azúcar crudo. También, para muchas fábricas, la capacidad de la estación de tachos es a menudo la estación que limita la tasa de molienda. Actualmente varios ingenios australianos tienen un único operador de la estación de tachos y una herramienta de gestión como el Sistema de control supervisorio inteligente, (SSCS) asiste al operador en la toma de las mejores decisiones. El SSCS integra las tasas proyectadas para meladura y mieles para cada tacho con la producción prevista de meladura basada en la recepción de caña y las mieles de las centrífugas. Usando la fase de cada tacho en un modelo operacional, se predicen los niveles de meladura, mieles A y B en los respectivos tanques y la información es usada para anticipar problemas o ineficiencias potenciales, de mantenerse las estrategias de operación vigentes. Un sistema experto basado en lógica fuzzy híbrida se emplea para recomendar procedimientos correctivos. Aunque el sistema no ha sido adoptado todavía comercialmente, cada fase del plan de desarrollo ha sido considerada. Los niveles de tanques emitidos por el sistema se comparan favorablemente con los niveles reales. El SSCS debe resultar en un mejor uso del equipo instalado en tachos para lograr incrementos en recuperación, mejor calidad de azúcar y menor consumo de vapor, manteniendo los requerimientos en cuanto a las tasas de producción. Un beneficio importante del sistema de control debe ser la reducción de la variabilidad en el consumo de vapor en tachos, lo que conduce a economías de vapor en la fábrica.
DEVELOPMENT OF DESCRIPTOR TOOLS FOR THE CHARACTERISATION OF AUSTRALIAN SUGAR MILL EVAPORATOR SCALE

By

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KEYWORDS: Evaporator, Scale Composition, Chemical Cleaning.

Abstract
CLEANING of sugar mill evaporators is an expensive exercise. Identifying the scale components assists in determining which chemical cleaning agents would result in effective evaporator cleaning. The current methods (based on x-ray diffraction techniques, ion exchange/high performance liquid chromatography and thermogravimetry/differential thermal analysis) used for scale characterisation are difficult, time consuming and expensive, and cannot be performed in a conventional analytical laboratory or by mill staff. The present study has examined the use of simple descriptor tests for the characterisation of Australian sugar mill evaporator scales. Scale samples were obtained from seven Australian sugar mill evaporators by mechanical means. The appearance, texture and colour of the scale were noted before the samples were characterised using x-ray fluorescence and x-ray powder diffraction to determine the compounds present. A number of commercial analytical test kits were used to determine the phosphate and calcium contents of scale samples. Dissolution experiments were carried out on the scale samples with selected cleaning agents to provide relevant information about the effect the cleaning agents have on different evaporator scales. Results have shown that by simply identifying the colour and the appearance of the scale, the elemental composition and knowing from which effect the scale originates, a prediction of the scale composition can be made. These descriptors and dissolution experiments on scale samples can be used to provide factory staff with an on-site rapid process to predict the most effective chemicals for chemical cleaning of the evaporators.

Introduction
The sugar industry experiences scaling of evaporators; the extent of scaling varies from mill to mill, within a season and from season to season for individual evaporators. These encrustations are formed from the combined effects of several processes involving inorganic and organic molecules or ions.

The type of the scale formed depends on a number of parameters, including the concentrations of scale-forming ions, the amount of dissolved and suspended solids, the pH and flow properties of the solution, the rate of evaporation, and the operating temperature (and pressure) of the system.

Impurities in juice deposit onto heating surface areas because heating surface areas have a higher temperature at their surface than the surrounding juice and provide nucleation sites for scale growth. Scale facilitates the corrosion of surfaces, restricts fluid flow and, because it has low thermal conductivity, its accumulation on metal surfaces impairs heat transfer across the metal-fluid interface.
One of the most important characteristics of any evaporator set is to ensure that it can evaporate water from the juice at an adequate rate to ensure that the set does not become the rate-limiting step in the factory.

After a clean, evaporator sets typically have sufficiently high average heat transfer coefficients to meet the rate of production. However, as the heating surfaces become covered with scale, the heat transfer coefficients (HTC) decline, and if the set is heavily fouled it will not always meet production rates.

This is particularly so in Australian sugar factories where spare evaporators are not available and fouled effects cannot be taken off-line for cleaning without interrupting factory operation. In these circumstances, some limited options are available to reduce the impact on the factory. Options such as the reduction of maceration water on the milling train, lowering of the syrup brix set point and the reduction of filter wash water help to maintain the required evaporator rate. However, these techniques can only sustain the evaporator set for a certain period and ultimately the only option is to stop the factory so that the evaporators can be cleaned.

Cleaning of evaporators is an expensive exercise. The estimated cost associated with scale formation and scale removal for a typical Australian mill is $400,000 per season. This estimate comprises the costs of: (a) labour due to extended season; (b) factory shutdown causing loss of production, and (c) cleaning chemicals.

The factory stoppage time for cleaning of the evaporator set and the operating time between cleans depends on various factors such as the nature of the scale, type of cleaning chemical and the cleaning procedure adopted (Doherty, 2000). Identifying the compounds present in scale helps in determining which cleaning agents would result in effective cleaning of evaporators and which scale inhibitors will significantly reduce scaling rates (Crees et al., 1993).

Scale consists of many components and its composition can best be determined using a combination of techniques. Applicable techniques include atomic absorption spectrophotometry, x-ray powder diffraction (XRD), x-ray fluorescence (XRF), ion exchange/high performance chromatography, thermogravimetry/differential thermal analysis and electron microscopy (Crees et al., 1992 and 1993). This project aims to characterise scale samples with some of these techniques with the ultimate aim to describe the type of scale in each evaporator by visual and tactile descriptors, simple elemental analysis and dissolution experiments with cleaning chemicals currently used in Australian sugar mills.

Scale formation

Figure 1 illustrates typical distributions of the components in scale (as mass percent), relative to the position in the evaporator set and brix concentration of the juice. The data are based on scale analyses conducted by Sugar Research Institute in Australian sugar mills over the last 15 years.

The distribution trends are similar to those reported by Honig (1963). A large portion of scale formed has calcium as an elemental constituent due to an excess of calcium that is introduced into the process via liming prior to clarification. Any residual calcium that remains in the juice after clarification has the potential to contribute to scale formation in the evaporators, pans and fugals.

In general, in any evaporator set, the calcium phosphate and hydroxyapatite (a phosphate compound) content in scale decreases from the first to the last vessel, while the amorphous silica, calcium oxalate, calcium sulfate and aconitate content increase from the first to the last vessel. Solubility of amorphous silica and calcium oxalate are known to decrease with increasing sucrose concentration and reducing temperature leading to prevalence of these scales in the latter effects (Crees et al., 1992; Walthew and Turner, 1995; Doherty, 2000). Organic matter is present in all scales, but in decreasing proportions towards the end of the evaporator set.
Experimental

Scale collection

Samples of scale from calandria tubes were obtained by mechanical means from seven Australian sugar mills during the 2001 crushing season. The samples are further classified with mills A, B and C from the northern growing region, mills D and E from the central growing region and mills F and G from the southern growing region.

These samples were obtained both before and after the calandria tubes had been chemically cleaned, depending on the flexibility of the factory. In most cases though, scale samples were collected with a mechanical device (scale sampler) which allowed samples to be collected prior to cleaning or during maintenance stops without the need for the vessels to cool down considerably. The scale samples were collected from quintuple sets.

Scale characterisation

XRF and XRD analysis

The scale samples were thoroughly washed with distilled water to remove residual sugar and then dried to constant weight under vacuum prior to analysis. They were characterised using XRF and XRD. The elements were analysed using an x-ray fluorescence spectrometer equipped with a Radium tube. The x-ray studies were carried out using a Riagaku camera and a x-ray generator with CuKα radiation of wavelength 1.5418 Å. X-ray powder diffraction techniques were used as they are the standard methods for the identification of scale components.

Visual and tactile descriptors

The scale samples that were analysed by XRF and XRD were also characterised based on their visual and tactile appearance. The appearances of the scale samples were detailed as powder, granular or flakes. The texture of the scale samples was assessed by rubbing them between the fingers and was described as smooth, coarse, rough or gritty. A visual assessment of the colour of the scale was also made. To obtain the original colour of the scales present in the evaporators, it was
necessary to treat the collected scale samples with water since dehydration during storage might affect their colour.

**Scale dissolution**

Dissolution experiments using a proprietary Sugar Research Institute procedure were conducted in the laboratory on scale samples with the following chemicals:

- 10% (w/v) caustic soda solution.
- 3% (w/v) sulphamic acid.
- 10% (w/v) ethylene diamine tetra-acetic acid tetra-sodium salt (EDTA).

The dissolution experiments enabled generalised deductions to be made on the effect the cleaning agents have on individual scale components.

**Scale characterisation by simple chemical means**

The aim of scale characterisation by simple chemical means is to enable factory staff to quickly and cheaply determine the elemental composition of scale samples. The two main inorganic elements (apart from silicon) present in scale are calcium and phosphorus. Standard test kits used for the determination of phosphorus and calcium in boiler feedwater are available in the market and can be used by persons with little background chemistry knowledge. Preliminary assessments were conducted on four analytical test kits. The Hach test strips and the Nalco orthophosphate octet colour comparator were assessed for phosphate determination, while the Merck calcium analytical test strips and the Nalco hardness test kit for total hardness and calcium hardness (drop titration method) were assessed for calcium determination.

Scale (0.1 g), HCl (5 mL of 10% solution) and distilled water (15 mL) were placed in a 250 mL conical flask and heated to boiling. The solution was further boiled for 30 min with 5 mL water aliquots added from time to time. The solution was filtered through a Whatman No. 91 paper and transferred to a 1 L volumetric flask and made to the mark with distilled water. The scale solution was diluted with distilled water by a factor of five prior to phosphorus and calcium analysis.

**Results**

**Scale characterisation**

*XRF and XRD analysis*

The XRF results gave the elemental composition of the scale samples based on their metal oxides (SiO$_2$, Al$_2$O$_3$, Fe$_2$O$_3$, MgO, CaO, Na$_2$O, P$_2$O$_5$, and SO$_3$). The XRF data also gives a loss on ignition value due to the volatilisation of organic acids, lipids, proteins, polysaccharides, chemically bound –OH and H$_2$O as well as adsorbed water. The results from the XRF showed:

- CaO, P$_2$O$_5$ and SiO$_2$ were the main oxides identified in the scale samples.
- The highest proportion of P$_2$O$_5$ was present in the earlier effects (i.e. Nos. 1, 2 and 3).
- There was a reasonable amount of Fe$_2$O$_3$ in the scale samples. The presence of large amounts of Fe$_2$O$_3$ in some of the scale samples is probably due to corrosion of the tube plates.
- Each scale sample contains a large amount of organic matter as deduced from the loss on ignition.

Interpretation of the XRD patterns of the scale samples identified the following compounds: amorphous silica, hydroxyapatite, iron oxide, calcium carbonate, calcium oxalate (mono- and di-hydrate). Table 1 shows data for the seven factories on the approximate proportion of the scale
components determined by simple mass balance calculations and the XRD and XRF data for Nos. 1, 4 and 5 effects.

The results are summarised as follows:

- When SiO₂, P₂O₅, Fe₂O₃ and SO₃ are present in the scale, it has been established that SiO₂ is present as amorphous silica; P₂O₅ is present as hydroxyapatite, Fe₂O₃ is present as iron oxide and SO₃ is present as calcium sulfate di-hydrate.
- High CaO levels in Nos. 4 and 5 effects suggest the presence of calcium oxalate.
- Amorphous silica, hydroxyapatite and organic matter are the main scale components deposited in the No. 1 effect with hydroxyapatite as the largest scale component.
- Amorphous silica, calcium oxalate and organic matter are the main scale components deposited in the later effects with calcium oxalate and silica the largest scale components.

Table 1—Composition of scale in the Nos. 1, 4 and 5 effects of several Australian factories.

<table>
<thead>
<tr>
<th>Compound (%)</th>
<th>Mill</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No. 1 Effect</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amorphous silica (hydrated)</td>
<td></td>
<td>10</td>
<td>14</td>
<td>5</td>
<td>27</td>
<td>16</td>
<td>11</td>
<td>35</td>
</tr>
<tr>
<td>Hydroxyapatite</td>
<td></td>
<td>57</td>
<td>26</td>
<td>2</td>
<td>50</td>
<td>43</td>
<td>50</td>
<td>30</td>
</tr>
<tr>
<td>Iron oxide</td>
<td></td>
<td>2</td>
<td>23</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Calcium carbonate</td>
<td></td>
<td>8</td>
<td>11</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Calcium oxalate (mono- &amp; di-hydrate)</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Calcium sulfate</td>
<td></td>
<td>2</td>
<td>trace</td>
<td>trace</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Organic matter</td>
<td></td>
<td>21</td>
<td>26</td>
<td>84</td>
<td>21</td>
<td>39</td>
<td>35</td>
<td>29</td>
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<tr>
<td><strong>No. 4 Effect</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amorphous silica (hydrated)</td>
<td></td>
<td>8</td>
<td>16</td>
<td>36</td>
<td>trace</td>
<td>35</td>
<td>6</td>
<td>69</td>
</tr>
<tr>
<td>Hydroxyapatite</td>
<td></td>
<td>10</td>
<td>1</td>
<td>10</td>
<td>3</td>
<td>11</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>Iron oxide</td>
<td></td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>trace</td>
<td>trace</td>
<td></td>
</tr>
<tr>
<td>Calcium carbonate</td>
<td></td>
<td>trace</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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</tr>
<tr>
<td>Calcium oxalate (mono- &amp; di-hydrate)</td>
<td></td>
<td>64</td>
<td>66</td>
<td>40</td>
<td>70 (di)</td>
<td>35</td>
<td>73</td>
<td>9 (di)</td>
</tr>
<tr>
<td>Calcium sulfate</td>
<td></td>
<td>trace</td>
<td>trace</td>
<td>0</td>
<td>0</td>
<td>trace</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Organic matter</td>
<td></td>
<td>16</td>
<td>12</td>
<td>13</td>
<td>26</td>
<td>18</td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td><strong>No. 5 Effect</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amorphous silica (hydrated)</td>
<td></td>
<td>42</td>
<td>24</td>
<td>27</td>
<td>32</td>
<td>78</td>
<td>67</td>
<td>40</td>
</tr>
<tr>
<td>Hydroxyapatite</td>
<td></td>
<td>9</td>
<td>1</td>
<td>9</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Iron oxide</td>
<td></td>
<td>trace</td>
<td>7</td>
<td>trace</td>
<td>trace</td>
<td>3</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Calcium carbonate</td>
<td></td>
<td>1</td>
<td>23</td>
<td>0</td>
<td>16</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Calcium oxalate (mono- &amp; di-hydrate)</td>
<td></td>
<td>33 (di)</td>
<td>38</td>
<td>31 (mono)</td>
<td>42</td>
<td>11</td>
<td>2 (di)</td>
<td>34 (di)</td>
</tr>
<tr>
<td>Calcium sulfate</td>
<td></td>
<td>1</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Sodium hydroxide*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>22</td>
</tr>
<tr>
<td>Organic matter</td>
<td></td>
<td>14</td>
<td>7</td>
<td>11</td>
<td>9</td>
<td>6</td>
<td>17</td>
<td>13</td>
</tr>
</tbody>
</table>

* The scales were collected after caustic clean.

The results are in agreement with the data in Figure 1. The results also show some variation across the various cane growing regions. Provided similar farming practices are used and similar cane varieties are grown, the scale composition should be reasonably similar over subsequent seasons but the concentrations of the scale components may vary due to changes in phosphate, calcium and organic acid content of the juice.
Visual and tactile descriptors

Some general trends were determined for the visual and tactile descriptors of the scale samples as follows:

- The colour of the scale samples is usually darker in the earlier effects than the later effects of an evaporator set.
- Dark coloured (chocolate brown/black) scale contains mainly hydroxyapatite and organic matter, while creamy coloured scale contains mainly calcium oxalate or is a mixture of calcium oxalate and amorphous silica.
- There was no marked change in colour between the ‘dry’ and wet scales, although the wet scale was darker in some samples.
- Flakes tended to be present in the last effects and were mixtures of calcium oxalate and amorphous silica.
- There was no discernible pattern on the texture of the scales across an evaporator set, other than at some factories the scales in the earlier effects were softer than those in the later effects.

Scale dissolution

The dissolution experiments showed that when the scale contained two main compounds with different chemical properties (e.g. hydroxyapatite and organic matter) a two-step cleaning process was required to completely dissolve the scale sample. The results are presented in Table 2 and confirm the earlier work of Doherty (2000).

<table>
<thead>
<tr>
<th>Compound</th>
<th>Effect of cleaning agent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic matter (proteins, degraded cellulose, polysaccharides etc.)</td>
<td>Readily attacked by caustic soda; not attacked by acid and EDTA</td>
</tr>
<tr>
<td>Calcium phosphate (tri-calcium phosphate and hydroxyapatite)</td>
<td>Readily attacked by acid; partially attacked by caustic soda and EDTA</td>
</tr>
<tr>
<td>Calcium carbonate</td>
<td>Readily attacked by acid and EDTA; not attacked by caustic soda</td>
</tr>
<tr>
<td>Amorphous silica</td>
<td>Slowly attacked by caustic soda; not attacked by acid or EDTA</td>
</tr>
<tr>
<td>Calcium oxalate (calcium oxalate mono-hydrate and calcium oxalate di-hydrate)</td>
<td>Readily attacked by EDTA; partially attacked by acid; not attacked by caustic soda</td>
</tr>
<tr>
<td>Calcium magnesium aconitate</td>
<td>Readily attacked by EDTA; slowly attacked by acid; very, very slowly attacked by caustic soda</td>
</tr>
</tbody>
</table>

Elemental analysis

Descriptions of the analytical test kits and preliminary testing results are given in Table 3. The kits were first tested on a series of standard solutions (made from sodium orthophosphate and calcium chloride) containing varying amounts of phosphate and calcium ions to determine the ease of use and any practical issues involved with the analytical procedure.

<table>
<thead>
<tr>
<th>Element</th>
<th>Type of test kit</th>
<th>Working conc. range (ppm)</th>
<th>Comments on use with standardised solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>P (as PO₄)</td>
<td>Hach test strip</td>
<td>0–50</td>
<td>Easy to use, but large concentration increments with small changes in colour reduce accuracy</td>
</tr>
<tr>
<td></td>
<td>Nalco colour comparator</td>
<td>1–100</td>
<td>Produced acceptable values for qualitative determination</td>
</tr>
<tr>
<td>Ca</td>
<td>Merck test strip</td>
<td>0–100</td>
<td>Provide approximate concentration. Concentration increments on the colour scale are quite large with no distinction between 10 and 25 ppm calcium</td>
</tr>
<tr>
<td>Ca (as CaCO₃)</td>
<td>Nalco hardness drop titration method</td>
<td>5–600</td>
<td>Produced acceptable values for qualitative determination</td>
</tr>
</tbody>
</table>
The results in Table 3 showed that the Nalco colour comparator can be used to determine the concentration of phosphate in scale, while the Nalco hardness drop titration method can be used to determine the concentration of calcium in scale. Table 4 shows the comparison of the phosphate (expressed as $P_2O_5$) and calcium (expressed as $CaO$) results obtained with the Nalco test kits with those obtained from XRF for a number of scale samples.

**Table 4—Scale analysis with Nalco test kits.**

<table>
<thead>
<tr>
<th>Scale origin</th>
<th>% $P_2O_5$</th>
<th>% $CaO$</th>
</tr>
</thead>
<tbody>
<tr>
<td>XRF</td>
<td>Nalco colour</td>
<td>XRF</td>
</tr>
<tr>
<td>No. 1 effect Mill E</td>
<td>18.1</td>
<td>19</td>
</tr>
<tr>
<td>No. 2 effect Mill G</td>
<td>12.5</td>
<td>8</td>
</tr>
<tr>
<td>No. 5 effect Mill G</td>
<td>1.5</td>
<td>0.4</td>
</tr>
</tbody>
</table>

The results show differences between the Nalco test methods and the XRF method. The differences of the $P_2O_5$ results between the Nalco colour method and the XRF method were not very large. As such, the Nalco colour method for phosphate may be used to determine the $P_2O_5$ content of scale. Marked differences were obtained in the calcium results. These differences may be due to certain components in the scale interfering with the Nalco hardness test method. Also, the colour change (from reddish-purple to bluish purple) for the Nalco hardness test method was broad and hence the end-point was difficult to detect. As a result, the Nalco hardness test, though suitable to analyse calcium in simple solutions, is not recommended for calcium determination in scale.

**Development of scale and cleaning tools**

The data obtained from the various scale analysis characterisation methods (XRF and XRD analyses, visual and tactile descriptors, scale dissolution and elemental analysis) allow the development of scale descriptor information data sheets for typical scale types present in Australian sugar mill evaporators.

The conclusions from the tactile studies were that it was not an effective method to identify different scale types since the textures of most of the scale types were similar. Nonetheless, the tactile data were included in the data sheets. These data sheets are summarised in Figures 2 to 4 for the scale samples obtained from the Nos. 1, 4 and 5 evaporators.

As chemical analyses of scale samples are expensive and can not be completed in a timely manner, the aim was for the portfolio of data to serve as a reference for factory staff to qualitatively assess the scale composition based on the colour and appearance of the scale. This will assist in the prediction of appropriate and effective chemical cleaning agents to be used in the different effects to remove scale.

The following steps should be undertaken to characterise an unknown scale sample and to propose a cleaning procedure:

**Step 1.** Identify sample source e.g., No. 1 effect.

**Step 2.** Identify the colour of the sample (note whether the sample is wet or dry).

**Step 3.** Identify the appearance of the sample.

**Step 4.** Based on the results of steps 1, 2 and 3 refer to scale descriptor data sheets containing No.1 scale.

**Step 5.** Based on the results of step 4 propose a cleaning procedure by referring back to the scale descriptor data sheets.

**Step 6** The proportions of the mail scale components may be different from those represented in the data sheets. Therefore, it may be necessary to determine the calcium and phosphorus contents.
It should be noted that the data sheets are not comprehensive as only one set of scale samples was obtained from each mill at varying times through the 2001 crushing season and the composition of scale is known to vary as the crushing season progresses (Doherty, 2000). Certain types of scale may also look the same but have different compositions that will impact on the efficacy of cleaning agents. For example the scale obtained from No. 1 effect at mill G is similar in appearance and texture to the scale obtained from No. 4 effect at mill D; however, one scale is readily attacked by acids and the other by EDTA. Knowing from which effect the scale originates provides an extra parameter that can be used with generalised trends shown in Figure 1 that may allow a more accurate prediction of the scale composition.

**Fig. 2—Descriptors, composition and solubility of the scale from the No. 1 evaporators.**

**Fig. 3—Descriptors, composition and solubility of the scale from the No. 4 evaporators.**
Granular

Coarse
Cream & brown

Flakes

Coarse
Cream & light brown
Grey speckled

Powder
Cream

Appearance

Texture

Colour (wet)

Granular Appearance
Coarse Coarse Smooth Coarse Smooth Texture

Cream & brown Cream Cream & light brown Cream & brown Grey speckled Cream Colour (wet)

D CaC₂O₄, Silica
B CaC₂O₄, CaCO₃
A, C* CaC₂O₄, Silica
E Silica
G CaC₂O₄, Silica
E Silica

Mill
Major scale (>20%)
component
Minor scale
component

EDTA Acid/Caustic
EDTA Acid/Caustic
EDTA Acid/Caustic
EDTA Acid/Caustic
EDTA Acid/Caustic

Chemical attack*
Substantial
Partial

*Based on laboratory dissolution experiments: 10% w/v caustic; 10% w/v EDTA; 3% w/v sulphamic acid
CaC₂O₄: Calcium oxalate (mono- & di-); CaCO₃: Calcium carbonate; Phosphate: Tri-calcium phosphate [Ca₃(PO₄)₂] and hydroxyapatite [Ca₅(PO₄)₃OH];
Silica: amorphous and crystalline silica
* After caustic clean

Fig. 4—Descriptors, composition and solubility of the scale from the No. 5 evaporators.

Discussion

The procedures adopted by different mills to control scale in their evaporators vary in the choice and concentration of chemicals, the length of cleaning time and the degree of cleaning obtained. If the evaporator has sufficient monitoring of operating and process parameters, then the HTC can be calculated and used to determine the degree of cleaning obtained and the effectiveness of cleaning chemicals used (Broadfoot and Dunn, 2007).

Alternatively, visual inspection of the heating surfaces enables a similar indication of cleaning effectiveness but requires adequate sight glasses and lighting to observe the evaporator heating surfaces following a clean or that the evaporator is opened for access which takes time and labour. Simple probes could also be developed to allow on-line sampling of scale to overcome these issues.

The cleaning protocol recommended from the present study involves the use of one cleaning chemical at a time. In certain situations, it has been found that this cleaning procedure has yielded unsatisfactory results. This occurs when the composite scale is made up of different layers/regions with different compositions. This has recently been illustrated from scanning electron microscopy and energy dispersive spectroscopy studies on scale in an evaporator tube which showed two different types of morphologies in a composite (East and Doherty, pers. comm., 2009).

Figure 5 shows poorly formed bi-pyramidal calcium oxalate di-hydrate crystals covered by a silica layer with smaller silica ball particles dispersed in the composite matrix. Such a scale matrix can only be effectively removed by the use of a formulation made up of caustic soda and EDTA. EDTA on its own will not dissolve or dislodge calcium oxalate scale that is covered by a layer of silica. However, caustic soda will readily attack the silica layer exposing the oxalate layer to EDTA attack.

Conclusions

Results have shown that, by identifying the chemical elements of scale and knowing from which evaporator vessel the scale originated, a prediction of the scale composition can be made. If the elements silicon, phosphorus, iron and sulfur are detected, then their associated chemical compounds can be predicted. It is not as straightforward with calcium. This is because calcium is
present in a number of chemical compounds and so the use of x-ray powder diffraction becomes necessary. However, in many situations, high calcium levels in Nos. 4 and 5 effects of a quintuple evaporator set suggest the presence of calcium oxalate.

![Fig. 5—Scanning electron micrograph of silica/calcium oxalate dihydrate composite in an evaporator tube.](image)

The visual descriptor studies have shown that if the origin of the scale is known, the colour and the appearance of scale can be used to qualitatively assess the scale composition. Dark coloured scale usually contains hydroxyapatite and organic matter, while creamy coloured scale contains calcium oxalate or is a mixture of calcium oxalate and amorphous silica.

When the scale is flake-like in appearance, it is likely to be a mixture of calcium oxalate and amorphous silica. The conclusions from the tactile studies were that it was not an effective method to identify different scale types since the texture of most of the scale types was coarse.

The paper presents a methodology for developing reference information on the scale types present in evaporators for factory staff based on various scale characterisation techniques. The database of information can add to the experience of factory staff that may enable a useful reference to determine effective and appropriate chemicals for cleaning purposes.

**Acknowledgements**

The funding provided by the Sugar Research and Development Corporation and a syndicate of Australian sugar mills is acknowledged. The assistance provided by a number of mills in collecting scale samples is also appreciated.

**REFERENCES**


**Résumé**

Le nettoyage des évaporateurs de sucreries est un exercice onéreux. L’identification des composants des incrustations aide à déterminer les meilleurs produits chimiques pour le nettoyage. Les méthodes actuelles (diffraction des rayons x, chromatographie liquide à échange d'ions/haute performance et l'analyse thermique thermogravimétrie/différentielle) utilisées pour la caractérisation des incrustations sont difficiles, onéreuses et ne peuvent pas être effectuées dans un laboratoire d'analyse conventionnel ou par le personnel du moulin. Cette étude a examiné des descripteurs simples pour la caractérisation des incrustations dans des évaporateurs australiens. Des échantillons d’incrustations provenant de sept évaporateurs australiens ont été obtenus par des moyens mécaniques. L'apparence, la texture et la couleur des incrustations ont été notées; les échantillons ont été caractérisés à l'aide de fluorescence de rayons x et diffraction de poudre de rayons x, pour déterminer les composés présents. Un certain nombre de kits de test analytique commerciaux ont été utilisé pour déterminer le contenu de calcium et phosphate des échantillons. Des expériences pour étudier la dissolution ont été effectuées sur les échantillons avec les agents de nettoyage sélectionnés, pour fournir des informations pertinentes sur l'effet des agents de nettoyage. Les résultats montrent que, en identifiant tout simplement la couleur et l'apparence des incrustations, leur composition élémentaire et de savoir de quel effet l’incrustation est issue, une prévision de la composition de l'incrustation peut être faite. Ces descripteurs et les résultats des expériences de dissolution donnent au personnel d’usine un processus rapide, sur place, pour prédire les substances chimiques les plus efficaces pour le nettoyage chimique des évaporateurs.
DESARROLLO DE HERRAMIENTAS DE DESCRIPTOR PARA LA CARACTERIZACIÓN DE INCRUSTACIONES EN EVAPORADORES EN AUSTRALIA

Por

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PALABRAS CLAVE: Evaporador, Incrustación, Limpieza Química.

Resumen
LA LIMPIEZA de evaporadores en un ingenio es una operación costosa. La identificación de los componentes de la incrustación ayuda en la determinación de los agentes químicos eficaces para la limpieza. Los métodos actuales (basados en técnicas de difracción de Rayos X, intercambio iónico/HPLC y termogravimetría/análisis térmico diferencial) usados para la caracterización de incrustaciones, son difíciles, costosos, consumen tiempo y no pueden ser ejecutados en un laboratorio de análisis convencional o por el personal de planta. Este trabajo ha examinado el uso de pruebas simples de descriptor para la caracterización de las incrustaciones en evaporadores australianos. Se obtuvieron muestras de incrustación por medios mecánicos de siete evaporadores. La apariencia, textura y color se registraron antes de caracterizar las muestras usando fluorescencia de Rayos X y difracción de polvos en Rayos X para determinar los compuestos presentes. Se utilizaron varios kits de pruebas analíticos y comerciales para la determinación de fosfatos y calcio en las muestras. Se hicieron experimentos de disolución con agentes de limpieza química para determinar sus efectos sobre diferente tipo de incrustación. Se demostró que simplemente identificando el color y la apariencia de la incrustación, la composición elemental y cual efecto se analizaba, podía hacerse una predicción de la composición de la incrustación. Estos descriptores y experimentos de disolución pueden ser utilizados para suministrar información rápida y formular los químicos para la limpieza de los evaporadores.
IRON MEDIATED CLARIFICATION AND DECOLOURISATION OF SUGARCANE JUICE

By

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KEYWORDS: Colour, Removal, Clarification, Iron.

Abstract

IN ORDER TO operate most profitably, the sugar producers in Louisiana wish to engage in a cooperative arrangement with the sugar refineries. Because the sugar refinery is an industrial scale decolouriser that operates using natural gas as fuel, it makes sense that sugar with less colour, produced using bagasse-power, would likely have greater profit margins. The removal of phenolic colorants from raw juice using native cane protein as a vehicle and Fe$^{3+}$ as an oxidative catalyst was studied. Colour was removed as phenol-protein conjugates which rapidly precipitated with the addition of a cationic flocculant. The decanted juice was clarified via cold-liming. The treatment yielded clarified juice with up to 70% lower colour than hot-liming juice. It appears that the phenolics were oxidised by Fe$^{3+}$ which engaged a REDOX cycle yielding quinoid species. The free N-$\varepsilon$-amino groups of lysine in the albuminoid proteins appeared to add to the quinones. Stoichiometry indicated a degree of polymerisation of eight. Oligomer formation ceased at this length which appeared sufficient to facilitate irreversible cross-linking and/or capping of the protein. The aggregates of iron, lignol(s) and protein were insoluble and precipitated. The process was tested in a 150 L settling clarifier which was operated in both pulsed and continuous modes. The method scaled well and the product juice exhibited 50–60% less colour than a cold-limed control when Fe$^{3+}$ was applied in quantities ranging from 100–200 mg/L.

Introduction

Commercial cane sugar in the U.S. is refined from a raw sugar (~800–2500 IU) to yield a product with a colour of 15–50 IU. This arrangement is currently in a state of flux as global competition is encouraging vertical integration of the industry (Brady, 2005). Refineries use natural gas to power their operations. The white sugar premium is approximately 6.6 cents (Todd, 1997) per kg but the cost of natural gas can offset as much as 39% of this premium. The cost of the fuel used to process raw sugar is integrated with the price of cane. This price differential is pushing refiners to demand lower colour raw sugar to reduce their cost of refining.

The prohibitive expense associated with the implementation of affination in the raw sugar mill makes alternative options attractive. A wide variety of techniques and additives have been tested to either improve clarification and/or reduce the colour of raw sugar. A comprehensive review has been presented elsewhere (Madsen, 2006). There are no industrial-scale decolourising processes operating at raw sugar mills in the United States. The base technology is in the form of the carbon and resins that are used in refinery facilities.

It has been noted that the phenolic materials present in sugar originate in the cane. Removal of these materials from the juice will prevent them from propagating through the process. The colour load of the clarified juice rapidly saturates decolourising carbon which necessitates frequent regeneration via kilning (thermal desorption). This can be surmounted by a chemical regeneration process (Bento, 2006; Rein and Bento, 2006).
Additives can be used to bleach or inhibit colour formation in processing streams or on sugar. For example, hydrogen peroxide has been considered as a pre-treatment method for resin/carbon decolourisation (Bento, 2004) or as a bleach for sugar when applied directly (Saska, 2006). Iron salts can be used to effect clarification and decolourisation when used in tandem with ultrafiltration (UF), peroxide, sulfitation and/or conventional liming procedures. A hybrid decolourisation/clarification method similar to the work presented here was reported by Zerban (1921) who applied 20 ppm of Fe$^{3+}$ and observed little effect. A patent (Madsen et al., 1984) describes the use of ferric chloride as a chelant/oxidant. The agent served to create floc which was removed via ultrafiltration and the resulting liquor was hot-limed.

Iron is present in cane, and some 30–40% (Seip, 1947) of it is extracted into the juice during milling. Additional iron enters the juice as soluble salts (Subbarao, 1935) via the action of acidity upon mild steel piping and equipment. The total amount is about 10–20 mg Fe per L (van der Poel et al., 1998) of juice. This iron is implicated in the formation of colour in cane juice, presumably via formation of both coloured complexes and oxidation products (quinones and polymer) with intrinsic phenolic compounds (Riffer, 1986). This mechanism can be exploited to effect coagulation of the phenolic colorants which could facilitate removal via UF.

Described in this work is a process where ferric iron is used, in conjunction with a cationic flocculant and conventional cold-liming to reduce juice colour without the use of carbon, resin or ultrafiltration.

Materials and methods

**Iron clarification: Settling rate of flocs from raw juice**

Raw juice was treated with an aqueous solution of Fe$^{3+}$ as FeCl$_3$ (Mallinckrodt, hexahydrate, 99.8%). The material was standardised against a five-point curve (EM, IX0230-2, 1000 mg/kg Fe$^{3+}$ in HCl, $R^2 = 0.9999$), as the Fe$^{3+}$ tris(o-phenanthroline) complex via absorbance (Beckmann Coulter DU-800) at 510 nm. The determination was made both with and without hydroxylamine as a reductor. By difference, it was determined that the working solution, made with 18 MΩ de-ionised water, contained 49 232 mg/kg of iron, 1.71% of which was Fe$^{2+}$. This solution was used in all subsequent tests.

Directly following the addition of Fe$^{3+}$ to raw juice, the mixture was stirred and cationic polyamine (Ecolab PCS-3106) was added at 10 mg solid/kg juice. The polyamine content of the liquid preparation was determined via gravimetry to be ~60 g/100 g.

Immediately following the addition of the cationic flocculant, the juice was stirred and poured into an Imhoff cone and the settling rates were determined using a stopwatch. The time was marked onto the cone and the supernatant juice was collected via syringe. The supernatant was weighed and expressed as the mass percent of juice recovered/time. Mud was defined as the difference.

The mud was filtered through a coarse paper and the filtrate was mixed with the decantate. The mixed juice was brought to a pH of 7.1 with slaked lime (Ca(OH)$_2$ 5g/100g) and then rapidly brought to boil using a microwave oven. To the boiling mixture was added anionic polyacrylamide (Magnafloc LT-340), 5 mg/kg as polymer). This mixture was settled as before to yield a clarified juice. The juice was adjusted to pH = 7±0.1, filtered through 0.45 μm membrane filter and colour was measured by absorbance at 420 nm. This process was repeated for the samples containing 50–600 mg/kg Fe$^{3+}$, in 50 μg/g increments.

**Pilot Test**

Briefly, the ‘dual clarification’ method involved:

1. Treatment of raw juice, at ambient temperature, with approximately 150 mg/L Fe$^{3+}$ and 10–15 mg/L of cationic flocculant.
2. Settling of this mixture to yield ‘stage-1’ juice.
3. Stage-1 juice was limed ‘cold’ to pH 7.1 and rapidly boiled.
4. To this was added up to 5 mg/L anionic flocculant. The mixture was settled to provide a decolourised, ‘stage-2’ juice.

A pilot-scale settling clarifier was constructed to hold approximately 150 L of juice and was designed to operate continuously at approximately 7.7 L/min. The clarifier was used to test the efficacy of the iron mediated clarification and decolourisation (FeMCaD) process. The equipment used for this work can be seen in Figure 1.

The goal was to evaluate the colour removal both in batch (single-tank of juice dosed at once) and continuous modes of operation (steady-state with in-line addition of chemicals).

In the batch tests, the iron was added in increments from 0 to 50, 100, 150 and 200 mg/L in 150 L of raw juice. In continuous mode, the clarifier was brought to steady-state. The 150 L vessel was fed raw juice at 7.7 L/min. Iron and cationic flocculant were dosed to supply 150 and 15 mg/L, respectively. The stage-1 juice was taken off at a rate of 6.7 L/min and mud was removed via a progressive cavity pump at a rate of 1.0 L/min.

![Fig. 1—Pilot clarification module tested at Raceland (2007 campaign).](image)

**Irreversible coagulation and a covalent mechanism**

Protein, fraction V bovine serum albumin (BSA, Cohn fraction V), was used to make a solution that delivered 9.04E-8 mMol/μL (5853 μg/g) in de-ionised water. Acetate buffer (1 M) was prepared from de-ionised water and sodium acetate and was adjusted to pH 5.00±0.05 (Oakton 11 series with Ag/AgCl probe) using glacial acetic acid (Mallinkrodt, AR).

A model phenolic compound, 3,4-dihydroxycinnamic acid (caffeic acid, CFA), was used to make a solution of 4.95E-5 mMol/μL (8825 μg/g) in a degassed matrix consisting of absolute ethanol and water, 1:1.
A solution was prepared from analytical grade sucrose (Fisher, ACS, 99.8% $\left[\alpha\right]_D^{25}=+66.5^\circ$) and 18 MΩ de-ionised water.

This solution contained 40 g/100 g (brix) and was standardised by refractometry (Bellingham and Stanley RFM340). With dilution, this solution was used as the base for the model solutions.

A 0.2 M phosphate buffer solution (PBS) was prepared by dissolving 9.36 g NaH$_2$PO$_4$, and 32.73 g Na$_2$HPO$_4$ into 1 L of de-ionised water. Eluent for gel permeation chromatography (GPC) was prepared using 250 mL of this solution and 17.53 g NaCl diluted to 1 L.

The eluent contains 50 mMol PBS and 0.3 M NaCl, at pH= 7.0±0.1. This solution was degassed under vacuum (24’ Hg) with sonication prior to use.

In order to establish the stoichiometry that exists between BSA, CFA and Fe$^{3+}$, the aforementioned materials were used to prepare a series of samples according to the matrix given in Table 1. The amount of BSA applied to each sample equates to 9.04E-5 mMol of protein or 5.42E-3 mMol of N-ε-NH$_2$-lysine. Fe$^{3+}$ was added at 5.65E-3 mMol, a slight excess over the BSA amino equivalent.

The samples CFA 3 and 7 (bold text), represent one and two equivalents of CFA, respectively. To 15 mL polyethylene centrifuge tubes was added, in this order: water, sucrose solution, BSA solution, CFA solution, AcONa buffer and, finally, FeCl$_3$ solution.

The samples were sealed and swirled (vortex mixer) to mix and allowed to stand at room temperature (24°C) for 10 minutes. The samples were centrifuged at 3600 r/min for 10 min. The tubes were sampled and analysed via GPC.

The operational parameters for the GPC are given in Table 2. The instrument was standardised for molecular weight using apro tinin (6.5 kDa), carbonic anhydrase (29 kDA) and BSA (66.4 kDa) via absorbance at 280 nm.

A quantitative calibration was made using a mixed standard containing BSA and CFA. Since only one wavelength is available at a time, 330 nm was chosen because it is an absorbance maxima for caffeic acid ($R^2=0.997$). BSA has a very small absorbance at this wavelength, so quantitation could be made using the DRI ($R^2=0.995$).

The samples were analysed via GPC. The plots acquired using the DRI were not used because the BSA rapidly fell below the limit of quantitation. Under the conditions specified in Table 2, caffeic acid had a retention time of 14.68±0.04 minutes.

A response factor (amount/area) of 6.022E-05±4.7% was used for quantification. The points at 200, 390, 568, 780, 992, and 1204 µg/mL represent 1.0, 2.0, 3.0, 4.0, 5.1 and 6.2 BSA (60 * LYS) equivalents, respectively.
Table 2—GPC parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pump</td>
<td>Waters 510</td>
</tr>
<tr>
<td>Detector 1</td>
<td>Thermo Differential Refractive Index (DRI), 45°C</td>
</tr>
<tr>
<td>Detector 2</td>
<td>Applied Biosystems UV-VIS, 330 nm</td>
</tr>
<tr>
<td>Detector hold-up time</td>
<td>1 minute, DRI to UV-VIS</td>
</tr>
<tr>
<td>Column</td>
<td>Shodex Protein KW-903, 300 mm X 4.2 mm (ID), 5 μm, 40°C</td>
</tr>
<tr>
<td>Eluent</td>
<td>50 mMol PO₄ buffer, pH 7.0±0.1 and NaCl, 0.3 M, 1 mL/min</td>
</tr>
<tr>
<td>Degasser, autosampler</td>
<td>Perkin Elmer, Vacuum; BioRad AS3500</td>
</tr>
<tr>
<td>Acquisition/run-time</td>
<td>Dionex ACI, Dionex Peaknet 5.2, 30 min</td>
</tr>
<tr>
<td>6.5, 29, 66.4 kDa, min</td>
<td>16.17, 12.53, 9.45</td>
</tr>
<tr>
<td>Quantity BSA, 7.29 min</td>
<td>491, 978, 1949 μg/g, RF= 1.12E-3, R² =0.995</td>
</tr>
<tr>
<td>Quantity CFA, 14.68 min</td>
<td>115, 203, 397 μg/g, RF= 1.26E-5, R² =0.997</td>
</tr>
</tbody>
</table>

Results and discussion

Decolourisation, given in Figure 2, reconstructed using equation 1, was dependent upon the dose of Fe³⁺. The limitation imposed upon the decolourisation process is the mud pack volume.

This is illustrated in Figure 3, which describes the behaviour of the mud-pack relative to the Fe³⁺ dose. Decolourisation reached a maximum of 60% using decantation for mud removal. The mud-pack volume was 20% greater than that observed with the standard clarification process.

![Graph](image-url)
The colour reduction, the colour removed relative to the control, was dependent on the amount of iron applied. This relationship appears to follow the following empirical equation, where Fe\(^{3+}\) is the amount of iron added in mg/kg.

\[ \text{Colour removed,\%} = \left( \frac{\text{control colour} - 35289 \times Fe^{3+}{-0.32}}{\text{control colour}} \right) \times 100 \tag{1} \]

It was noted during the bench scale trials that, although the decolourisation continues to improve as iron levels are increased (up to a point), the settling rates decrease (and mud-pack volume increases). This can be seen in Figure 3 for juice settled for 20 minutes.

![Graph showing the relationship between Fe\(^{3+}\) and juice recovery](image)

\[ y = -9E-05x^2 + 0.0211x + 60.464 \]
\[ R^2 = 0.974 \]

Fig. 3—Juice recovered in 20 minutes when increasing iron dosages beyond 200 mg/L.

In the laboratory, the juice can be filtered or centrifuged to provide a sample for analysis. Because this would be uneconomical to do in the mill, it was decided that dosing to 150–200 mg/L to provide a decolourisation of up to 50% was a practical limit.

While type/brand of anionic flocculant demonstrated little variation, the cationic materials were not equivalent. For example, products such as the Cytec Superflocs (regardless of charge density) performed marginally, while the PCS-3106 was exemplary.

A chart displaying the removal of juice colour, relative to a cold-limed control is given in Figure 4. The decolourisation % for each bar is calculated relative to a control taken at the same time from a tap preceding the dosing points on the clarifier module.

The behaviour of the pilot scale process is similar to that observed at bench scale and decolourisation behaves in a manner similar to that described by equation 1.
The two step process yielded a low colour juice similar to what can be seen in Figure 2. After 45 minutes, the mud had a settled volume of 26 mL/100 mL. This volume of mud contained approximately 1.2 g of dry solids which was similar to that recovered during the bench-scale trials plotted in Figure 3.

The overall colour reduction, in pulsed tests, versus raw juice clarified by cold-liming (control) was approximately 50% when the iron was applied at 150–200 mg/L. When the iron dose exceeded this amount, the settling rate decreased. Thus, a dosage of 150 mg/L of iron was selected for tests where the clarifier would be operated continuously. The results were consistent with those achievable in the lab, in terms of dose-response and an equivalent nominal colour removal of ~50%.

The clarifier operated without incident for approximately six hours. During this time, the juice was collected, along with a concomitant control, limed, brought to boil using a microwave, flocculated (5 mg/L anionic flocculant) and settled to yield stage-2 juice which was assayed for colour.

This juice exhibited a level of decolourisation which was comparable to that observed in the batch test at equivalent dosage. It was concluded that the two-stage method scales well and can provide a clarified juice with 50% less colour than that achievable with normal hot or cold-liming procedures.

It was found that if cane juice is treated with iron, cationic flocculant and cold-limed, up to 50% of the colour in the juice can be removed at the clarifier. The liming step must take place before the juice is heated. If this order is reversed, the sucrose inverts and the juice will form colour on contact with air. The treated juice can then be limed and clarified normally.

The samples in Figure 5A appear to be identical. Upon the addition of the iron, it was immediately noted that samples containing two BSA equivalents (1.1E-2 mMol) of CFA precipitated immediately. The samples in Figure 5B were centrifuged. The precipitation of coloured material in Figure 5C is striking and increases with the amount of added CFA. Upon standing sealed for three days, all samples containing at least 1 BSA equivalent (5.4E-3 mMol) precipitated completely. The precipitate pellets in Figure 5D appear smaller because the mixtures were re-centrifuged to settle the flocs that had formed.
Fig. 5—Addition of iron and centrifugation of model samples. 148 and 375 μg/mL CFA correspond to CFA 3 and 7.

The amount of CFA consumed, expressed in Figure 6 in mg/L, inset, reached a maximum at 200 and was resolved at 500 μg/mL CFA. This is equal to 0.005 mMol and is very close to 1 N-ε-lysine BSA equivalent (0.0054 mMol).

Fig. 6—Amount of CFA consumed. Note the plateau (steady state) and point of saturation (inset).
From this it appeared that at least two, simultaneous reactions were occurring. The first suggests a saturation effect and the second suggests polymerisation. Between 7.971 and 8.333 BSA equivalents of CFA are needed before the rate of consumption stabilises. Approximately 14.5 equivalents are needed before the amount of CFA detected equals the amount that was applied.

The plot in Figure 6 suggests that there is a fast initial consumption of CFA which ended when ~1 lys-BSA equivalent, or 0.05 mMol of CFA was added. This suggests that the free sites are reacting/binding until saturation. Following this, there is a short induction period, possibly the accumulation of an undetectable intermediate, followed by a linear increase in consumption. This implies that either the residues added in the prior step are reacting with further CFA and removing it from the bulk solution or the CFA is homopolymerising.

It appears that first, the free N-ε-amino-lysine groups are reacting with the phenolic species, probably in the quinone form. Then, the quinone end-groups are reacting further to extend phenolic chains outward. This continues until either the CFA reservoir is exhausted and/or the chains extending from two separate proteins meet and couple.

From the stoichiometry given in Figure 6, where the maximum CFA consumed amounts to 0.0343 mMol, it can be derived that the equivalence to BSA is approximately 380:1. On free amino-groups this amounts to a ratio of 6:1. There appears to be, depending upon the cross-linker used, of the 60 lysine residues in BSA, approximately 8–12 are able to crosslink with the N-ε-NH₂ lysine(s) of other protein molecules in the bulk solution (Huang et al., 2004).

If the number of chains per protein is, on average, 10, the CFA to amino group ratio then becomes 38:1. Dividing this figure by two, for two interacting protein molecules gives a bridge length or degree of polymerisation of approximately 8.

Upon examination of the stage-1 (acidic Fe³⁺) process under a microscope, it was found that the application of 6 M urea failed to disrupt the floc, and the addition of EDTA caused only a marginal disassociation. Addition of o-phenanthroline caused the flocs to become larger and more robust. This is demonstrated in Figure 7. GC-MS analyses of mixtures of juice and phenanthroline with and without iron indicated that the ligand was either removed from solution or otherwise destroyed.

The failure of 6 M urea to disrupt the floc argues that little in the way of hydrogen bonding is responsible for the stability of the BSA:CFA aggregates. The very slight disruption observed when the aggregate was treated with EDTA indicates that some, but not all of the structure is likely dependent upon chelation of iron. The effect of added o-phenanthroline was unexpected.

Rather than causing the material to disintegrate (at least partially) due to sequestration of any bound iron that might be structural, the addition of o-phenanthroline caused the flocs to become larger (Figure 7). Unsure of this result, the juice was treated with “excess” o-phenanthroline with
and without added FeCl₃. These samples were analysed via GC-MS and revealed a marked (>90%) removal of the ligand. In order to explain this, it was found that Cavalieri et al. (2002) had reported on the electrophilic addition of o-quinone species to purine bases in DNA. The reaction involves the radical semiquinone and is functional over a relatively wide range of pH, including physiological. An adapted scheme is given in Figure 8.

![Fig. 8—Synthesis and reaction of a o-quinone with a purine base.](image)

This scheme (Figure 8) is in line with observations. Instead of using cyp (cytochrome P) 450, Fe³⁺ serves as the initial oxidant to yield the semiquinone which is subsequently subject to autooxidation via O₂. The resulting quinone then reacts with the purine base to yield the adduct.

We were unable to confirm that the o-phenanthroline was behaving in a similar way. It was suspected that the compound, being difunctional, might be serving a crosslinking species. Because the aggregates appear to be covalent in nature, they are irreversibly formed. This irreversible nature indicates that the flocs once made, may be stable through liming, removing the need for the second stage of the process. With cold liming, it might be possible to do both steps, sequentially, in one reactor.

**Conclusions**

Ferric chloride can be used to remove phenolic compounds from cane juice via coagulation. As iron dosage is increased, the amount of floc increases as the settling rate decreases. Addition of cationic polyacrylamide improves the settling rates allowing for higher iron dosages to be used. Under the best conditions, it appears that a removal of approximately 50% (55±4%) of the colour can be practically achieved while maintaining a satisfactory degree of clarification within 20 minutes of settling.

The method scaled well and performed as predicted by the bench-scale experiments. It was found that the 50% reduction of colour (relative to a cold-limed control) was achieved with the application of 150–200 µg/mL Fe³⁺ and then liming to pH 7.1.

The mechanism appears to be a mixture of classical charge-neutralisation, complexation and covalent linkages between the phenolic compounds and native albuminoid protein found in the juice. The aggregates made via charge-neutralisation can be disrupted via addition of further coagulant while the complexes are labile to changes of pH, treatment with o-phenanthroline and/or application of urea. The flocs made here were especially resistant to the action of urea, were insensitive to pH and were demonstrated to aggregate with and remove o-phenanthroline.

This action was tested on BSA using varied amounts of the phenolic surrogate compound caffeic acid. It was found that the rate of consumption increases until flocs are no longer observed to form. At this point, steady consumption dropped to zero and the process was considered complete.

The observed consumption revealed an initial saturation of the protein which occurred at 200 µg/mL CFA. This corresponded to the number of free N-ε-amino groups from BSA. Following this, the rate of consumption increased until 1500 µg/mL of CFA had been consumed. At 2250 µg/mL, the rate of consumption drops to zero and the reaction is complete. Based on the number of N-ε-amino groups present, it was elucidated that crosslinks formed between the proteins which were between 6 and 10 phenolic residues in length.
REFERENCES


CLARIFICATION INTERMÉDIAIRE POUR LE FER ET LA DÉCOLORATION DU JUS DE CANNE

Par

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MOTS CLEFS: Couleur, Réduction de Couleur, Clarification, Fer.

Résumé
POUR AMÉLIORER la rentabilité, les producteurs de sucre en Louisiane souhaitent coopérer avec les raffineries de sucre. Étant donné que l’opération principale de la raffinerie est de réduire la couleur et que la raffinerie fonctionne à l'aide de gaz naturel comme combustible, il est logique que le sucre avec moins de couleur, produit à partir de bagasse, donnerait de meilleurs gains financiers. L'élimination des matières colorantes phénoliques du jus brut à l'aide de protéines présentes dans la canne et du Fe$^{3+}$ comme un catalyseur oxydatif, a été étudiée. La couleur a été supprimée grâce à la précipitation de composés phénol/protéine cause par l’addition d'un floculant cationique. Le jus décanté a été clarifié par le chaulage à froid. Le traitement a donné un jus clarifié avec une couleur réduite par 70% comparée au jus provenant d'un chaulage à ébullition. Il semble que les phénoliques ont été oxydés par le Fe$^{3+}$ à travers une réaction RÉDOX produisant des quinoides. Les groupes N-ε-amino libres de lysine dans les protéines albuminoïdes s’ajoutent aux quinones. La stoichiométrie a indiqué un degré de polymérisation de huit. La formation d’oligomères cesse à ce point ce qui facilite la réification irréversible de la protéine. Les agrégats du fer, lignol(s) et protéines étaient insolubles et sont précipités. Le processus a été testé dans un décanteur de 150 litres qui a été exploité en mode pulsé et continu. La méthode à bien fonctionnée et le jus produit présentaient 50–60% moins de couleur compare à un contrôle chaulé à froid, avec 100-200 mg/l Fe$^{3+}$ ajoute au jus.
CLARIFICACIÓN CON HIERRO Y DECOLORACIÓN
DE JUGO DE CAÑA

Por

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PALABRAS CLAVE: Color, Remoción, Clarificación, Hierro.

Abstract
PARA OPERAR en un modo más rentable, los productores de azúcar en Louisiana desean emprender un arreglo cooperativo con las refinerías de azúcar. Debido a que una refinería es una estación reductora de color a escala industrial que opera usando gas natural como combustible, tiene sentido que un azúcar de menos color, producido usando energía del bagazo, pueda dar mejores márgenes de ganancia. Se estudió la remoción de colorantes fenólicos del jugo crudo usando proteína de la caña como un vehículo y Fe³⁺ como un catalizador oxidante. El color fue removido como conjugados de fenol-proteína que precipitaron rápidamente con la adición de un floculan te catiónico. El jugo decantado fue clarificado vía encalado en frío. El tratamiento dio jugo claro con hasta 70% menos color que el jugo encalado en caliente, Parece que los fenólicos fueron oxidados por Fe³⁺ el cual entró en un ciclo REDOX produciendo especies quinoides. Los grupos libres N-ε-amino de lisina en las proteínas albuminoides parecieron sumarse a los quinoides. La estequiometría indicó un grado de polimerización de ocho. La formación de oligómeros cesó en esta longitud que parece suficiente para facilitar ligado cruzado irreversible y/o capping de la proteína. Los agregados de hierro, lignoles y proteína resultaron insolubles y precipitaron. El proceso se probó en un clarificador sedimentador de 150 L que operó en modo pulsante o en modo continuo. La escalabilidad del método fue buena y el jugo mostró 50–60% menos color que uno encalado en frío cuando se aplicó Fe³⁺ en cantidades entre 100–200 mg/L.
PROCESS SYNTHESIS AND MANAGEMENT IN THE BOILING HOUSE OF SUGAR FACTORIES

By

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KEYWORDS: Sugar, Boiling, Modelling, Scheduling, Synthesis.

Abstract

IN THE BOILING house of sugar factories, the process manager may conduct the process through different ways due to the batch mode of operation of vacuum pans, the need for cutting over materials among pans to achieve the required crystal sizes, and the different types of materials that must be handled, some of which are recycled. The process manager addresses most of his efforts to this area since he must try to reach the required standards of quality in end-products and the expected yields, but meanwhile he must also keep a stable steam demand and accumulation of intermediate materials in adequate quantities to maintain a steady operation. A new approach for synthesis and management (material and energy balances, scheduling) of the processes on the pan stage for sugar production from cane is presented and its advantages demonstrated in this paper. Detailed models and approaches for process synthesis and operations management on the pan stage of sugar factories are described. These models are the basis of the software tool PLANAZUCAR® dedicated to the scheduling of complex production systems in the sugar industry. Approaches include the use of HAZOP techniques and other software tools. Through actual case studies, the feasibility of using the software tool PLANAZUCAR for scheduling analysis in the sugar industry was demonstrated. Use of the software has allowed a thorough study of the utilisation rates of the equipment in a factory as well as an analysis of the influence of the production planning on the steam consumption profile, looking for stability in demand.

Introduction

From the process operation point of view, the pan stage differs from other areas of the factory. Whereas most stations operate in a continuous way, most pans do not. The main task of the production manager is to ensure that this batch-wise part of the process operates as steadily as possible, since the efficiency of sugar recovery and maximum processing of raw materials depend on the co-ordination of operations, use of recycled materials, use of equipment, etc. A very important aspect for pan stage operation is the stabilisation of steam demand.

For years these management tasks have been accomplished by process managers using tools which they developed themselves through practice and heuristically. Modern approaches for process synthesis and management in this area have been studied.

Aguado (1973) published a paper proposing a discrete programming model for scheduling of operations in vacuum pans. De Armas and Rostgaard (1983) proposed another approach: that of representing this problem as an activity network with limited resources and the use of linear programming (LP) for solving the materials balances.

The Monte Carlo method was used to predict duration times of activities during simulation runs to establish the more probable way of conducting operations in the boiling house. Since then,
simulation languages and dynamic programming methods have been used. All these jobs had limitations in representing the whole process.

In this paper, three case studies introducing new models for process synthesis in both raw and refined sugar production from cane are presented. Two of them are used for operations scheduling and another, at operations level, is proposed for material balances linked to the operations schedule.

**Case study 1: The EON approach**

This approach is based on the definition of recipes describing tasks being done for sugar production on the pan stage. These recipes include information about operations that should be carried out and resources (materials, utilities) used by them. Operations are then assigned to equipment to represent a strategy to be simulated. The structure of the activities to be performed within each process is represented through a general activity network called Event Operations Network or EON (Graells et al., 1998). The rigorous modelling of the operation timing involved in the recipe is achieved by means of EON elements: events, operations and links.

Events designate time instants in which a change may occur. They are represented by nodes in EON graphs and should be linked also with other events. Each event is associated with a time value and a lower bound. The time values for each event will be the variables of the timing problem that must be solved. The lower bound can be used to force delays in a given solution or force a new solution fulfilling special constraints.

Operations designate those time intervals to be observed between the starting event (initial node) and the ending event (final node). Operations are expressed as equality links between nodes in terms of the operation time and the waiting time. The operation time is a pre-determined value as a function of the amount being processed, unit assigned, etc. The waiting time is a value below the maximum time a material could be stored in the vessel before discharge.

Finally, links designate event-event precedence constraints.

Thus the linear programming problem formulation may be defined by:

- Ending time of operation $i$ in stage $j$ in unit $k$ is equal to operation starting time plus operation duration time, plus waiting time.
- Starting time of operation $i+1$ in stage $j$ in unit $k$ is greater than or equal to the ending time of operation $i$ in the same stage and unit.
- If any two operations $i$ and $i^*$ corresponding to tasks $j$ and $j^*$ are done simultaneously in two $k$ and $k^*$ units and one depends on the other (such as transfer of material from one pan to another), then waiting time of operation $i$ in stage $j$ in unit $k$ is less than or equal to the maximum waiting time defined for that operation in that stage and unit.
- Duration time of operation $i$ in stage $j$ in unit $k$ is defined as a function of unit $k$ volume occupation during operation $i$ of task $j$.
- Consumption of material $l$ for each operation $i$ in every stage $j$ and unit $k$ is defined in the same way as the duration time.
- Lower and upper bounds for unit operating capacities.

An objective is needed to discriminate a good solution among the infinitely feasible solutions. A simple and practical one is minimising the total duration of the process which allows compressing the resulting schedules and improving capacity utilisation. This function takes into account durations of all operations done in the process.

The factory being studied produces 2000 tonnes per day of refined sugar, using a four massecuite processing system with double seed magma preparation in raw sugar production, producing ‘A’ sugar for the refinery and raw sugar for sales. In the refinery, a three massecuite processing system is used for the production of three qualities of refined sugar, while final molasses from the refinery is recycled to the raw sugar factory. In the raw sugar section of the factory, there
are 23 vacuum pans, 14 vessels for intermediate and final materials, 52 crystallisers and 35 batch centrifugals. In the refined sugar section, there are eight vacuum pans, six vessels for intermediate materials, 11 crystallisers and 17 batch centrifugals. Seventeen different materials are processed. All the mentioned equipment, materials and areas were included in the analysis, so the dimensions of both the models for material balances and scheduling were large.

The material and energy balance calculations were done using the SIMFAD software package (Sabadi et al., 1991). The mathematical model describing the process includes constraints for:

- Solids, total flows and pool balances;
- Mass fraction of sugar crystals contained in massecuite;
- Growth of sugar crystals from seed to commercial size;
- Steam and power demand in operations; and
- Other technological constraints based on operators’ experience.

The main purpose was to study the best co-ordination between vacuum pans, crystallisers and centrifugals to achieve an optimal equipment utilisation and to avoid any instantaneous high steam demand. The objective function used was to minimise steam consumption, both for raw and refined sugar production. All results, including those for purities of intermediate materials are in close agreement to the actual values in the plant.

Different boiling strategies were defined and 10 basic recipes were developed for raw sugar and six for refined sugar production strategies. Data regarding resource information and recipe definitions were used to perform the calculations that end up into a desired production plan.

In sugar boiling, the duration of the operation depends on the crystal growth which is not a fixed value. A closer representation to reality is reached using the Monte Carlo simulation method based on the historical average values of task duration and their variance. These values are used in PLANAZUCAR© 2.0 for randomly generating values for duration in order to select the most probable makespan of the process.

Manual modifications in the proposed schedule were done to evaluate the consequences of the changes performed. Timing of operations, predicted evolution of the level profiles of intermediate storage, prediction of the use of resources such as steam, etc., were considered. The Gantt chart in Figure 1 shows operations done in six of the pans in the factory, as a prediction over 32 hours.

![Gantt chart](image)

Fig. 1—Gantt chart for six pans showing materials generation and consumption.
It also includes the production consumption profiles for the final massecuites (MCC) as well as for the required and/or produced intermediate materials (first growth of seed crystals (SPC), syrup (MCOMP), A molasses (MAP), 1st purge, B molasses (MB1) and 2nd purge B molasses (MB2)) and vapour bleed from the evaporators (VVFC, also called ‘vegetal’ steam). These charts compare well with actual operations in the plant. The predicted number of batches is similar to those produced in the factory in the selected equipment for guaranteeing the final products demand.

The profiles of steam consumption for every stage of operation were determined. A highly variable steam demand was shown to exist, thus affecting the boilers and evaporator station in a negative way (Figure 2).

Fig. 2—Steam consumption profiles.

Despite this positive experience (Sabadi et al., 2005), some further improvements in the software were identified and introduced in PLANAZUCAR© 3.0:

- Equations used for consumption of utilities such as steam were improved by using second or third degree polynomial expressions.
- Objective function is optional and flexible; in each case study, the user can select the criterion to be satisfied.

Case study 2: The STN approach

The objective of this case is to evaluate the state task network (STN) approach (Kondili et al., 1993), which is a mixed integer linear programming model (MILP), in boiling schemes synthesis, through the software tools gBSS (Pantelides et al., 1993) and PLANAZUCAR© 3.0 (Hurtado and Sabadi, 2005). Although it is an actual case, its representation is not so detailed because it is oriented to evaluate the new approach and software instead of supporting actual decisions in the factory. The fundamental constraints to be satisfied include:

1. The resolution of conflicts when pans are allocated to tasks. At any given time $t$, a pan can only start at most one task. Of course, if a pan starts performing a given task, then it cannot start any other task until the current one is finished.

2. Limitations on the capacities of pans and storage vessels:
   - The amount of material $B$ that starts undergoing task $i$ in unit $j$ at time $t$ is bounded by the maximum and minimum capacities of that unit.
– The amount of material stored $S$ must not at any time exceed the maximum storage capacity $C_s$ for this material.

(3) Material balances. This constraint simply states that the net increase in the amount of a material stored at time $t$ is given by the difference of the amount produced and that used. The initial amount of each material is assumed to be known. All material inventories (including intermediate and final products) have to be specified for adjusting the model to the actual situation in the factory.

In a similar way, some other constraints may be included, extending the model:
1. Temporary unavailability of equipment.
2. Limited availability of utilities and materials.
3. Cleaning of equipment items.
4. Use of equipment items for storing task feeds.
5. Continuous feeds addition and products withdrawal.

As an objective function, the model is capable of accommodating a variety of either economic or system performance measures. The criterion mainly used in the present study is the maximisation of processed syrup.

Figure 3 represents the operation strategies in the production of massecuites. The circles represent the pans, identified by their number, and the other equipment (crystallisers and intermediate storage tanks for example) is represented by rectangles and other symbols. The arrows indicate the feeding and discharge of material. The high grade massecuites are boiled in seven pans while low grade massecuites are boiled in two pans.

Note that there is not a previous assignment of a particular equipment item to a task. Only the information on which tasks can be done in each equipment item is supplied. The solution includes the assignment of tasks to equipment items along horizon time.

Figures 4 and 5 show the results of the process synthesis for a 24 hours time horizon. In the Gantt chart, operations carried on in each equipment (pans, blender, centrifugals) are represented by blocks of different lengths according to their duration. Each operation is identified by a colour. Numbers inside the blocks identify batches and tasks.

Profiles of production and consumption of materials are shown in Figure 5. Massecuites are denoted by MCA, MCB and MCC, and molasses by MA, MB and MC. Intermediate materials in high grade massecuites are identified with an initial S and, in low grade massecuites, by an initial G. AA and AB are commercial raw sugars. Green colour in the profiles indicates no violation of
volume constraints and enough material for operations. A red colour profile indicates an unfulfilled condition.

Although all details of operations corresponding to each task were not defined, it is demonstrated that the model determines the definition and use of each task in the analysis for an optimal solution. Such a solution allows a more effective use of installed capacities due to the fact that an initial feasible solution is not required. Any solution reached must take into account real equipment connectivity in the factory to avoid mathematically feasible, but practically infeasible, solutions. This condition could be included in the mathematical model which can also accommodate equations for defining new piping and pumping installations for a solution. These options were not tested in the actual case study.

Using discrete variables in time representation (MILP) causes a bigger size of the problem, even for analysis of small cases. This case generated 593 equations for an 8 hour time span and 1905 equations for a 24 hour analysis. With gBSS and PLANAZUCAR 3.0, it is now possible to find solutions to these models.

**Case study 3: Balances at operations level**

The development of a non-linear mathematical model for material balance calculations in cane sugar production has been described (Ribas et al., 2002) as well as the software CALIFA©
(Hurtado et al., 2002), supported over such a model. The use of a LP model for the calculation of the material balance in sugar boiling for a specific configuration of pans has been described by De Armas and Sabadi (1993). That approach was used in a scheduling case study for a flow sheet of a three massecuite processing system for a sugar factory which also produced refined sugars based on an EON approach (Sabadí et al., 2001). A similar case study is used to allow comparison. In order to use the results in operations scheduling at the operator’s level, it is necessary to extend the balances to equipment at operations level.

In Figure 6, a non-detailed flow sheet corresponding to the operations level is shown. Nodes (geometric figures) represent the boiling operations, centrifugation, seed preparation and materials distribution; arrows represent flows among nodes and evaporated water. This representation is useful for balances in equipment at the operations level.

![Fig. 6—Flow sheet at operations level.](image-url)
Recipes at operational level were built for high and low grade massecuite production. These recipes describe the way in which operators conduct the operations in the selected equipment. All relevant tasks for producing the output material are included. Each task is described through its operations. The material balance for each recipe was usually introduced through coefficients related to one of the flows coming in or out of the recipe. In former exercises, those coefficients were calculated from an overall material balance for the process flow sheet and adjusted to the number of ‘trees’ required for a specified level of production of a certain material in a certain time interval (Sabadí et al., 2001). In this approach the material balance is done considering every individual operation, so the results are actually fitted to the equipment configuration and production strategy.

In this case, only values for eight variables need to be fixed, including the syrup flow, brix and purity to be processed. The rest of the values for the brix and purity of each flow are lower and upper bounded, based on actual experience and describe the characteristics of final products.

The model includes:
- total flow, solids and purities balances in each node;
- lower and upper bounds corresponding to limiting operating capacities in pans; and
- lower and upper bounds for intermediate storage vessels.

For this exercise, the maximisation of commercial ‘A’ sugar production was used as the objective function.

The results of the material balance for the strategy of production of ‘A’ massecuites, when compared with actual values, show no significant differences. The maximum value for commercial sugar production was 871.5 tonnes, and the value reported by the factory is 864.0. While the calculated ‘A’ massecuites is 2022.4, the value reported by the factory is 2013.0.

Similar comparisons can be done with results for the balances in ‘B’ and ‘C’ massecuites. The main benefit of this methodology is that these results are now easily, and more realistically, associated with the operations when facing a scheduling problem.

It is now possible to know the values for each stream going in and out of the pans and other vessels in each operation. So it is possible to conduct the process provided that the balances include the technological constraints which must be followed during operation for guaranteeing production and quality.

These material balance results can be compared to the corresponding Gantt chart representation of the process obtained with PLANAZUCAR® software tool and shown in Figure 7.
The operations for the ‘A’ massecuites are those in the first five lines of the chart (corresponding to pans 1, 2, 3 and 4 and the ‘A’ crystalliser called CRA). Operations for ‘B’ massecuites are done in pans 5, 6, 7 and 8, using crystalliser CRB. Operations for ‘C’ massecuites are done in pans 9, 10, 11, 12 and 13, using crystalliser CRC. Red colour in the blocks represents waiting time in operations.

With both results, the operator has a proposed schedule for the operations, including the values of the flows. He can guide the process knowing the time in which every operation must begin and the materials he should use to reach the expected results. In practice, it is very difficult to exactly follow the proposed schedule because of the possible occurrence of abnormal situations. So, operators must be well trained to face these problems. A hazard and operability (HAZOP) analysis would be a good basis for such training.

To represent the whole flow sheet of the process with this approach, a medium or large scale model must be built. Experiences with the SQP algorithm demonstrated that it is feasible to do it (Sabadí et al., 2003). To improve user exploitation of the software, it is recommended to include the automatic generation of the initial solution. The Powell algorithm for simultaneous solution of non-linear equation sets can be used for this aim (Sabadí et al., 1991). The lower and upper bounds for all streams could also be generated from this initial solution and improved, if necessary, based on estimates recommended by actual experience. Bounds such as lower and upper operating capacities of vessels and pans should always be provided by the user as well as the selected calculation basis.

Conclusions

Two new approaches have been studied for process synthesis and management of the boiling house of sugar mills: the event oriented and the state task networks, based on LP and MILP models. Both of these models have proven to be useful and included in PLANAZUCAR® 3.0 software. The usefulness of doing material balances at operations level when undertaking scheduling studies has been demonstrated. A model for such an analysis has been included in CALIFA® software. The next step in our work will be the creation of a software suite including the above mentioned tools and another one for hazard and operability analysis (HAZOP) in the boiling house.

REFERENCES


SYNTHESE ET ORGANISATION DE L’ATELIER DE CRISTALLISATION DE LA SUCRERIE

Par

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MOTS CLEFS: Sucre, Cuites,
Modélisation, Programme, Synthèses.

Résumé

Les operations de l’atelier de cristallisation peuvent être programmes de différentes façons, à cause des cuites discontinues, du coupage de massecuites, pour produire des cristaux de tailles voulus et pour manipuler des produits différents dont certains sont recyclés. Le Gestionnaire de processus concentre ses efforts dans ce domaine car il doit essayer d’atteindre les normes requises de qualité et les rendements attendus; il doit également maintenir une demande stable de vapeur et une accumulation de matières intermédiaires en quantités suffisantes pour permettre un fonctionnement stable. Une nouvelle approche de synthèse et de gestion (matériel et énergie) des processus est présentée et ses avantages démontrés dans ce document. On donne des modèles détaillés et des approches pour la synthèse et les opérations de gestion de la cristallisation. Ces modèles sont à la base de l'outil logiciel PLANAZUCAR® dédié à la planification des systèmes de production complexes dans l'industrie sucrière. On présente aussi d’autres techniques (HAZOP) et outils logiciels. La faisabilité de l'outil logiciel PLANAZUCAR dans l'industrie du sucre a été démontrée. L'utilisation du logiciel a permis une étude approfondie sur le taux d'utilisation de l'équipement dans une usine ainsi qu'une analyse de l'influence de la planification sur la consommation de vapeur et la stabilité de sa demande.
SÍNTESIS DE PROCESO Y GESTIÓN EN LA CASA DE COCIMIENTOS DE UN INGENIO

Por

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PALABRAS CLAVE: Azúcar, Cocimiento, Modelamiento, Programación, Síntesis.

Resumen
EN LA CASA de cocimientos de un ingenio azucarero, el jefe de elaboración puede conducir el proceso de diferentes formas debido al modo de operación de los tachos, la necesidad de repartir el material entre los tachos para obtener los tamaños de cristal requeridos, y los diferentes tipos de materiales que se deben manejar, algunos de ellos recirculados. El jefe de elaboración orienta la mayoría de sus esfuerzos en esta área dado que debe obtener las especificaciones requeridas de calidad en los productos finales y los rendimientos esperados, pero debe mantener una demanda estable de vapor y acumulación de materiales intermedios en cantidades adecuadas para mantener operación estable. Un nuevo enfoque para síntesis y gestión (balances de masa y energía, secuenciación) de procesos en la estación de tachos, se presenta en este trabajo junto con las ventajas de su adopción. Se describen modelos detallados y enfoques para síntesis de procesos y gestión de operaciones en la estación de tachos. Los modelos se basan en el programa PLANAZUCAR® dedicado a la programación de sistemas complejos de producción en la industria azucarera. Las aproximaciones incluyen el uso de técnicas HAZOP y otras herramientas informáticas. Se demuestra la aplicabilidad del programa PLANAZUCAR para análisis de programación en la industria azucarera usando el análisis de casos reales. Su uso ha permitido un completo estudio de las tasas de utilización del equipo en un ingenio así como un análisis de la influencia de la planeación de producción en el perfil de consumo de vapor, buscando estabilidad en la demanda.
COLOUR BEHAVIOUR IN CANE JUICE CLARIFICATION
BY DEFECATION, SULFITATION AND CARBONATION

By

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KEYWORDS: Sugarcane, Colour, Clarification,
Sulfitation, Carbonation.

Abstract

COLOUR is sugar’s most important commercial attribute but, in juice clarification, its
removal is usually not considered among primary objectives. However, based on results
presented, all standard clarification procedures have the potential for significantly
higher removal of colour than is realised in the industrial practice. Four principal juice
clarification procedures, viz. defecation by hot liming, sulfitation, carbonation and
double-carbonation were tested and various aspects of colour behaviour investigated.
Carbonation is not widely used in the cane sugar industry, but periodic spikes in sulfur
prices, sugar quality issues and environmental concerns have stimulated efforts to
consider replacing or supplementing sulfur dioxide with carbon dioxide that may be
available cost-free from the fermentation plant. The colour removal, viz. the relative
difference between colour of raw and clarified juice, obtained in our tests was on
average 35, 47, 44 and 74% for defecation, sulfitation, single-carbonation and modified
double-carbonation, respectively. Several factors affecting clarified juice colour in hot
liming were tested, viz. the time and temperature during settling; bagacillo and soil
content, and phosphate and protein addition. At low lime dose, below about 1 kg
CaO/tonne cane (defecation, sulfitation and carbonation), most colour removal results
from adsorption on the heat-coagulated cane protein, rather than on the nascent calcium
precipitate. However, the adsorptive capacity of the precipitate for cane colorants
appears only partially exhausted in the normal procedure. Lowering the clarifier
temperature by 11°C was found to limit the juice colour increase in the clarifiers to
nearly zero. Although the decolourisation effects of sulfitation and carbonation were
found to be about equal, the apparently lower thermal stability of clarified juice and
syrup produced by carbonation may require further study.

Introduction

The colour of sugar, be it raw, direct mill white or refined is its most important commercial
attribute, and much resource is spent by the millers and refiners to comply with the market
requirements on the colour of their product. Crystallisation itself, apart from producing a stable,
marketable product is also 95–99% effective in partitioning colour and is, in the production of low
colour sugar, supplemented by a number of carbon and ion-exchange resin-based adsorption
processes and, to a lesser degree, by methods based on chemical reactions that render colourless the
colorant molecules.

The main objectives of juice clarification are to raise its pH and eliminate suspended solids.
Colour removal is at best considered a secondary objective, rarely monitored by the mill laboratory
and to our knowledge never used as a criterion to assess, let alone control, the process. The use of
SO₂ is widespread in clarifying juice in production of plantation white sugar, however periodic spikes in sulfur prices and sugar quality issues have stimulated efforts to reduce or even eliminate its use. With that in mind, a carbonation process has been tested and compared with standard sulfitation and defecation. Besides eliminating the use of sulfur, carbonation would also provide a means to utilise and sequester some of the excess CO₂ that may be available cost-free in some sugar factories from molasses or juice fermentation. The traditional double-carbonation process was used initially in cane juice clarification in Java (Honig, 1959), later practised for many years in South Africa (Rault, 1960), and is still used nowadays in some cane factories in China, Taiwan (Sheen et al., 2003) and elsewhere. Although it is reported to provide excellent, low colour clarified juice, the very high lime consumption of 11–15 kg CaO per tonne cane is making the economics increasingly un-sustainable. In this program, some modifications were tested to reduce lime consumption and replace the filtration of all first carbonation juice by settling and filtration of the concentrated mud.

**Materials and methods**

In most cases, raw juice was prepared by milling samples of cane brought to Audubon from the Sugar Research Station. Usually, 0.6 to 0.8 L of pressed juice was diluted to 1 L volume to bring the brix closer to that of factory mixed juice, and clarified by four methods: defecation by hot liming, sulfitation, single carbonation or double carbonation.

For defecation, the diluted juice was brought to and kept boiling for about one minute in a microwave oven, then quickly limed while stirring with Ca(OH)₂ slurry to a pH between 7 and 8.2. Then 2.5 ppm of Ciba Magnafloc LT340 flocculant was added while stirring, the whole volume of limed juice transferred to a covered 1 L glass beaker and allowed to settle in a 96°C water bath, usually for 60 minutes, before sampling the supernatant for analysis.

Sulfitation was done in a 6 L stirred jacketed glass reactor provided with lime slurry and gas inlets, and pH and temperature readouts; usually by first liming 1 L of diluted juice at about 50°C to a pH of 8–9 and then gassing with SO₂ to a pH of about 7. Alternatively, gassing was done first to pH 3–4 followed by liming to pH 7. The clarification performance was about equal, but the former was preferred as it was considered to be more closely comparable with the carbonation tests where gassing with CO₂ must be done at alkaline pH (Figure 1) because of the negligible rate of absorption of carbon dioxide below pH 6. In either case, the sulfited and limed juice was heated and kept boiling for one minute, flocculant added and settling done as in defecation.

![Fig. 1—Absorption rate of carbon dioxide and sulfur dioxide in limed juice.](image-url)
Carbonation was done by liming the diluted juice in the 6 L stirred reactor kept at 50 to 60°C, to pH 8–9, kept at the high pH for 2 to 5 minutes and then gassed with CO₂ to pH 7–8, over about 5 minutes. The heating, flocculating and settling followed as before. The quantity of lime was maintained about the same in both sulfitation and carbonation to allow direct comparison between the two methods, and at levels comparable with those used in plantation mill white factories throughout South and Central America. In the following text, the pH measured at room temperature (about 25°C) is denoted as pH₂₅.

Double carbonation was done by preheating 1 L of diluted raw juice in the 6 L reactor to 50°C and liming with 3–5 g CaO to a pH 10.5–11. The pH was then reduced with CO₂ to about 10, temperature raised to 60°C, flocculent applied, and the mud settled for about 60 minutes to 25–30% of the initial volume. No precautions were taken to remove dissolved air from the juice. The supernatant from settling and filtrate from vacuum filtration of the thickened mud were combined and pH of the combined clear juice then reduced with CO₂ to pH 6.5–7. The carbonated juice was brought to boil and the small amount of the second carbonation precipitate removed by filtration under vacuum. The filterability of the first carbonation mud was measured with the same apparatus and mostly following the same procedure as before (Saska, 2005) in measuring filterability of clarifier mud. A temperature of 60°C was chosen, at 0.7, 1.4 and 2.1 x 10⁵ Pa pressure, a filtration area of 3.1 cm² with the support formed by a 20 µm stainless steel mesh and pre-coated with HyfloSuper Cel filter aid.

It is sometimes recommended that lime suspension be ‘aged’ before its use in juice clarification but, in these tests, the analytical grade Ca(OH)₂ that was used was mixed with water at about 1:10 ratio and used immediately. No adverse effects on settling or turbidity removal were noted.

All tests reported in this paper were done during the 2008–2009 season at ASI with juice extracted from the main varieties of cane nowadays grown in Louisiana (i.e. L 97-128, HoCP 96-540, LCP 85-384, etc.). However, other tests at EEAOC in Argentina (Zossi and Cardenas, 2009) have confirmed the validity of the present conclusions regarding the colour behaviour in clarification of juice produced from the two main cane varieties grown in Tucuman.

Results

Colour removal in clarification

The colour of raw juice ranged from 10 000 to 20 000 IU (Table A1 in the Appendix) with the variations reflecting effects of different cane varieties, cane conditions and the varied quantities of tops and green leaves crushed with the clean billets. The relative decolourisation, defined as 100 × (Colour of raw juice – Colour of clarified juice) / Colour of raw juice for defecation by hot liming, averaged 32%; sulfitation and carbonation were nearly equally efficient in terms of colour removal, with decolourisation of 45% and 42%, respectively (Table A2) with lime (CaO) consumption of about 0.7 and 0.9 g/L respectively versus the 0.5 g/L used in normal defecation (Table A1).

Although the colours of clarified and in particular of mixed juice are rarely measured in the factories, the limited available data (Eggleston, 2002; Sahadeo et al., 2002) indicate that the factory performance in terms of colour removal is substantially lower than the laboratory test results reported in Table 1 and in the Appendix Table A2.

Among the reasons for the difference between factory performance and laboratory decolourisation may be localised overheating or overliming in the industrial process, excessive residence times of juice or mud in the industrial heaters, clarifiers or filters, or other factors.

No systematic measurements were done of the mud settling characteristics. However, all three procedures produced well-settling mud with no apparent differences in settling rates among the three methods. Clarified juice turbidity varied mostly within the 50–150 NTU range, similar to
the range of industrial clarified juice and, as with mud settling rates, no systematic differences among the three clarification methods were observed. The large standard deviation of the CaO dose comes from the intentional variations introduced in the procedure to test the robustness and response of the process.

Table 1—Average colour before and after juice clarification, the lime dose used and relative decolourisation achieved.

<table>
<thead>
<tr>
<th></th>
<th>Colour, IU</th>
<th>CaO, g/L</th>
<th>Decolourisation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Avg</td>
<td>SD</td>
<td>Avg</td>
</tr>
<tr>
<td>Raw juice (N=26)</td>
<td>14</td>
<td>367</td>
<td>4113</td>
</tr>
<tr>
<td>Defecation (N=18)</td>
<td>9766</td>
<td>3668</td>
<td>0.5</td>
</tr>
<tr>
<td>Sulfitation (N=20)</td>
<td>7858</td>
<td>2821</td>
<td>0.7</td>
</tr>
<tr>
<td>Carbonation (N=17)</td>
<td>8351</td>
<td>3127</td>
<td>0.9</td>
</tr>
</tbody>
</table>

<sup>* different superscript letters (a or b) indicate a significant difference (p ≤ 0.05) between two data sets; while same letters indicate a statistically insignificant difference</sup>

Changes of juice pH and colour during settling

The composition of clarified juice and consequently the clarification method may have an impact on the rate of colour increase later in settling, during evaporation and in the vacuum pans. Thus thermal stability of the juice needs to be considered when evaluating clarification. To that effect, the residence time was varied from ½ to 4 hours for the three types of clarified juices (Table 2), at 96°C i.e. close to the average temperature in the industrial clarifiers, and at 85°C for clarified juice from hot liming, and its effect on juice colour and pH.

Table 2—Colour increase and pH drop during settling at 96°C and 85°C, for different clarification conditions.

<table>
<thead>
<tr>
<th></th>
<th>Colour, IU</th>
<th>CaO, g/L</th>
<th>Decolourisation*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Avg</td>
<td>SD</td>
<td>Avg</td>
</tr>
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<td>8351</td>
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</tr>
</tbody>
</table>

<sup>* Different superscript letters (a or b) indicate a significant difference (p ≤ 0.05) between two data sets; while same letters indicate a statistically insignificant difference</sup>

At 95°C, the colour increase in defecation and carbonation juices was found to be about equal, approximately 600 IU/h, but lower for juice produced by sulfitation. The pH drop during settling of defecation juices was found significantly higher than in sulfitation and carbonation.

Reducing the temperature from 96°C to 85°C during settling of defecation juice had a dramatic effect on colour formation rate and pH drop. Colour increase was reduced six-fold to less than 100 IU/h and the pH drop about two-fold.

Although not studied here, it is probable that comparable improvements would ensue in sulfitation and carbonation. It was suggested (Zossi et al., 2009) that this could be accomplished in the industrial process at a low cost by re-routing the vacuum filtrate that is now usually sent back to the mixed juice tank.

The limed juice would be heated and flashed as usual, but its temperature would then be reduced downstream of the flash tank by the cooler filtrate. This would be expected to reduce juice
colour and reduce the sucrose inversion loss, similar to the benefits derived from the short residence time clarifiers. Additional benefits are expected from avoiding recycling through the juice heaters the considerable amount of mud and flocculant contained in the generally poor quality filtrate.

**Thermal stability of syrup**

The rates of Maillard and other mechanisms responsible for colour formation are known to increase at lower water concentrations. Therefore, a series of ‘thermal storage’ tests at 70°C were also done with syrup following the same methodology as in the recent raw sugar storage tests (Saska and Kochergin, 2009). Syrup from each clarified juice was prepared in a glass laboratory ‘rotovap’ evaporator, under vacuum at 50–55°C. Colour increased in storage in each case (Figure 2); with the approximate slopes of 15, 9, 29 and 13 IU/h for defecation, sulfitation, carbonation and double carbonation, respectively.

![Graph showing colour increase of 60 – 70 brix syrup produced from the four different clarification procedures and stored at 70°C.](image1)

**Fig. 2**—Colour increase of 60 – 70 brix syrup produced from the four different clarification procedures and stored at 70°C.

![Graph showing pH drop during storage of syrup produced by the four different clarification procedures.](image2)

**Fig. 3**—pH drop during storage of syrup produced by the four different clarification procedures.
Because of the lower temperature, the rate of colour formation is much slower than in settling (Table 2), but the sulfitation syrup again exhibits the slowest colour increase of all. The pH drop (Figure 3) is about equal in all four cases, and apparently independent of the initial pH.

**Mechanism of colour removal**

It is usually assumed that, in juice clarification, any colour removal is due to adsorption of colorants on the nascent crystals of calcium phosphates and other sparingly soluble anions, in analogy to the more frequently studied colorant behaviour in sugar refining by phosphatation or carbonation. However, the few experiments that are summarised in Figures 4 and 5 indicate that adsorption on heat-coagulated cane protein may be the prevalent mechanism for colour removal in juice clarification. In the experiments in Figure 4, bringing the raw juice to boiling without any lime addition removed nearly 7000 IU or 39% of the initial colour. The full hot-liming and clarification done on the same juice only added another 6% to the total 45% decolourisation. When 100 mg/L aliquots of phosphoric acid were added to the mixed juice prior to liming, the colour removal by hot-liming increased by about 600 IU per aliquot.

![Fig. 4—Colour of raw juice, raw juice after boiling and clarified juice by hot liming after addition of phosphoric acid.](image)

In the experiment in Figure 5, cane protein was supplemented by sequential additions of bovine serum albumin (BSA), a structurally similar protein.

An addition to diluted raw juice of 1.5 g/L of protein increased the colour removal by hot liming by an additional 1500 IU. Another 3 g/L of BSA was added (for a total of 4.5 g/L) to the clear juice from this experiment, and the spiked juice was briefly boiled again; however, no additional lime was added.

The colour decreased by another 1300 IU. This was repeated one more time, for a total of 7.5 g/L of protein, with an additional 600 IU removed. It is therefore clear that both BSA and cane protein when heat-coagulated or during heat-coagulation have strong affinity for cane colorants.

The decolourisation effect, however, decreases with increasing dose of the protein; perhaps because the affinity of the protein is specific for only certain fractions among the wide variety of cane juice colorants. Unlike BSA, egg-white albumin was found ineffective in juice colour removal. Bagacillo or soil particles in only coarsely screened industrial cane juice have a substantial effect on the mud behaviour in clarifiers, most notably the former providing the bulk of the mud volume.
FIG. 5—Colour of raw juice, clarified juice by hot liming (control), and clarified juice after sequential additions of bovine serum albumin.

Whether they affect colour of clarified juice as has been sometimes alleged is less certain. The experiments summarised in Figure 6 indicate that neither has any detectable influence above the normal experimental variations. The added amounts indicated in Figure 6 are given in g dry matter/100 mL raw juice.

FIG. 6—Colour of raw juice (13 200 IU), juice clarified by hot liming (control), and juice clarified by hot liming after additions of bagacillo or dry mud to the raw juice.

The clarifier underflow is made up of 90–95% clarified juice with colour that one could assume identical to that of the clarifier overflow provided the residence times were comparable. However, some previous observations in factory tests (Saska, pers. comm., 2009) indicated that the colour of the ‘mud juice’, that is the juice entrained in, and recovered from the mud in vacuum filters, was on occasions actually lower than that of the overflow from the clarifiers. This prompted tests to determine the state of saturation of the adsorptive capacity of mud particles for colorants. In
the experiments reported in Table 4, cane juice was clarified by hot liming and its colour determined as usual (CJ colour and Decolourisation 1 in Table 4). The settled mud was then blended for a few seconds in a standard kitchen blender, solids separated by centrifugation, and the colour of the supernatant juice again determined by the standard method. In all, twenty experiments were done and are reported in Table 4; the colour of the supernatant from the blended mud (Mud colour and Decolourisation 2 of Table 4) always decreased, sometimes by up to 2700 IU. This is evidence that the adsorptive power of the hot-liming precipitate is not exhausted in the standard process.

Table 4—Colour of raw juice, juice after hot liming and of the ‘mud juice’ after blending the mud.

<table>
<thead>
<tr>
<th>RJ colour IU</th>
<th>CJ colour IU</th>
<th>Mud colour IU</th>
<th>Decolourisation 1 %</th>
<th>Decolourisation 2 %</th>
<th>Difference %</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 957</td>
<td>9986</td>
<td>7764</td>
<td>37</td>
<td>51</td>
<td>14</td>
</tr>
<tr>
<td>10 429</td>
<td>7742</td>
<td>35</td>
<td>51</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>9811</td>
<td>7575</td>
<td>39</td>
<td>53</td>
<td>14</td>
<td></td>
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<tr>
<td>10 000</td>
<td>7701</td>
<td>37</td>
<td>52</td>
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<td></td>
</tr>
<tr>
<td>17 390</td>
<td>8689</td>
<td>7473</td>
<td>50</td>
<td>57</td>
<td>7</td>
</tr>
<tr>
<td>8838</td>
<td>7331</td>
<td>49</td>
<td>58</td>
<td>9</td>
<td></td>
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<td>8919</td>
<td>7519</td>
<td>49</td>
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<td>Avg 55 b</td>
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*Different superscript letters (a or b) indicate a significant difference (p ≤ 0.05) between two data sets; while same letters indicate a statistically insignificant difference.

Blending the mud may expose internal surfaces of the precipitate, rendering them available to adsorb more colorant. It would seem, therefore, that potential exists for further improvements in decolourisation above the levels reported in Table 1.

Double-carbonation

In the modified double-carbonation procedure, the CaO dose was reduced on average to 3.1 g/L (Table 5), or about four-times greater than the present industrial process. Decolourisation at these conditions was 74% on average, with some values exceeding 80%. Clarified juice turbidity was less than 10 NTU, and Ca and Mg ions determined by ion-chromatography were about 500 and 200 mg/L, respectively.

Table 5—Average performance of the double carbonation clarification of cane juice.

<table>
<thead>
<tr>
<th>CaO added g/L</th>
<th>pH&lt;sub&gt;25&lt;/sub&gt; of CJ</th>
<th>Colour, IU</th>
<th>Decolourisation</th>
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<tr>
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<td>RJ</td>
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The filterability of the thickened first carbonated mud may be the critical parameter for the scale-up of the modified process. Therefore, the effects of various parameters, e.g. the quantity of lime used were measured. The filterability of the juice, thickened by settling to about 30% of the original volume, was found unaffected (Figure 7), and comparable with filterability of the standard hot liming defecation mud determined under identical conditions (Saska, 2005). The volume to be
handled by the filter station is greatly reduced, and its capacity in terms of tonnes of cane per day increased.

![Graph showing filterability of thickened mud from the modified process and the industrial double carbonation process.]

**Fig. 7**—Filterability of thickened mud from the modified process (solid lines) with 3 and 5 g/L of CaO, and that of the industrial double carbonation process with 12 g/L CaO (dotted line).

**Conclusions**

The average decolourisation that was achieved in juice clarification by defecation, sulfitation, single carbonation and modified double carbonation was 35, 47, 44 and 74%, respectively. However, available data indicate that decolourisation that is routinely achieved in defecation (Eggleston, 2002; Sahadeo *et al.*, 2002) and sulfitation factories (Zossi and Cardenas, 2008) is considerably less.

Replacement of SO₂ by CO₂ (carbonation) is feasible, achieving comparable decolourisation and mud settling characteristics, but the apparently lower thermal stability of clarified juice and syrup from carbonation requires more study.

The colour increase at conditions typical in industrial clarifiers was found to be about 600 IU/h for defecation and carbonation, and about 350 IU/h for sulfitation clarified juice. By reducing the settling temperature by 11°C, the colour increase could be reduced to less than 100 IU/h.

An indication was obtained that, in juice clarification, most decolourisation comes from adsorption of cane colorants onto heat-coagulated cane protein rather than onto the nascent calcium precipitate, and that some of the adsorption capacity remains unused in the standard process.

No significant effect was observed from either bagacillo or soil on colour removal in clarification.

Significant reductions of CaO consumption in the commercial double carbonation process to about 3 kg CaO/tonne cane are possible, in conjunction with thickening of the first carbonation mud by settling and polishing filtration after the second carbonation.

**REFERENCES**


http://www.cabdirect.org:80/abstracts/20033169851.html
### Table A1
Colour of raw and clarified juice obtained in different clarification procedures, and the lime dose used.

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Table A2—Absolute and relative colour removal in different clarification procedures (other conditions are given in Table A1).

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EVOLUTION DE LA COULEUR PENDANT LA CLARIFICATION DU JUS DE CANNE PAR DEFINICATION, SULFITATION ET CARBONATATION

Par

M. SASKA1, S. ZOSSI2 et H. LIU3

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MOTS CLEFS: Canne a Sucre, Couleur, Clarification, Sulfitage, Carbonatation.

Résumé

LA COULEUR est le plus important attribut commercial du sucre mais, à la clarification, sa réduction n'est pas considérée parmi les principaux objectifs. Cependant, toutes les procédures de clarification ont le potentiel pour une diminution plus élevée de la couleur que celle réalisée dans la pratique industrielle. Quatre procédures de clarification, notamment la définication par chaulage à chaud, le sulfitage, la carbonatation et la double carbonatation ont été testées pour étudier le comportement de la couleur. La carbonatation n'est pas beaucoup utilisée dans l'industrie du sucre de canne, mais des augmentations périodiques du prix du soufre, des problèmes de qualité de sucre et les préoccupations environnementales ont stimulés les efforts pour remplacer ou compléter le dioxyde de soufre par le dioxyde de carbone qui peut être disponible gratuitement a partir de l'usine de fermentation. La réduction de couleur entre le jus mélangé et le jus clarifié, obtenu au cours de nos tests était en moyenne 35, 47, 44% et 74% pour la définication, le sulfitage, la carbonatation simple et la double carbonatation, respectivement. La durée et la température au cours de la décantation, la présence de bagasse folle et du sol, l’ajout de phosphate et de protéines, tous des facteurs affectant la couleur de jus clarifié durant le chaulage chaud, ont été testés. À de faibles doses de chaux, en dessous d’un kg de CaO/tonne de canne (défécation, sulfitage et carbonation), la réduction de couleur se fait par l'adsorption sur les protéines de la canne coagulées par la chaleur, plutôt que sur le précipité de calcium. Toutefois, la capacité d’adsorption des colorants par le précipite n’est pas bien utilisée pendant la procédure normale. Abaisser la température du décanteur par 11°C limite l'augmentation de couleur du jus dans les décanteurs à presque zéro. Quoique que la décoloration du sulfitage et celle de la carbonatation soient plus ou moins comparables, la stabilité thermique apparemment inférieure du jus clarifié et du sirop produits par la carbonatation peut exiger une étude plus approfondie.
COMPORTAMIENTO DEL COLOR EN CLARIFICACIÓN DE JUGO DE CAÑA POR DEFECACIÓN, SULFITACIÓN Y CARBONATACIÓN

Por

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PALABRAS CLAVE: Caña de Azúcar, Color, Clarificación, Sulfitación, Carbonatación.

Resumen

El color es el atributo comercial más importante del azúcar pero, en clarificación de jugo, su remoción usualmente no es considerada entre los objetivos primarios. Sin embargo, con base en los resultados presentados todos los procedimientos estándar para clarificación tienen el potencial para la remoción significativa de color que lo considerado en la práctica industrial. Se probaron cuatro procedimientos de clarificación de jugo, defecación por encalado en caliente, sulfitación, carbonatación y doble carbonatación, y se investigaron varios aspectos del comportamiento del color. La carbonatación no se usa ampliamente en la industria del azúcar de caña pero los incrementos periódicos en el precio del azufre, aspectos de calidad del azúcar y preocupaciones ambientales han estimulado los esfuerzos para considerar el reemplazo o suplemento del dióxido de azufre con el dióxido de carbono, que puede estar disponible gratis de la planta de fermentación. La remoción de color, es decir la diferencia relativa entre color de jugos, crudo y clarificado, obtenida en las pruebas, fue en promedio 35, 47, 44 y 74% para defecación, sulfitación, carbonatación sencilla y doble carbonatación modificada, respectivamente. Se probaron varios factores que afectan el color del jugo claro en el encalado en caliente, como tiempo y temperatura durante la sedimentación, contenido de suelo y bagacillo y adición de fosfato y proteína. Con dosis bajas en el encalado, por debajo de 1 kg CaO/tonelada de caña (defecación, sulfitación y carbonatación) la mayor remoción de color resultó de la adsorción en la proteína de caña coagulada por calor en lugar que en el precipitado de calcio. Sin embargo la capacidad de adsorción del precipitado para los colorantes de la caña aparece sólo parcialmente agotada en el procedimiento normal. Se encontró que el descenso de 11°C en el clarificador limitó el incremento de color del jugo en los clarificadores a cerca de cero. Aunque los efectos decolorantes de sulfitación y carbonatación fueron prácticamente iguales, las aparentemente más bajas estabilidades térmicas del jugo clarificado y la meladura, producidas por la carbonatación, pueden requerir estudios posteriores.
MINIMISING OF DECOLOURISATION COST FOR INVERT CANE SYRUP PRODUCTION USING LOW COLOUR SUGARCANE VARIETIES

By

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KEYWORDS: Colour, Sugarcane, Variety, Purification, Decolourisation.

Abstract

PRODUCTION of invert cane syrup is an alternative diversification product from sugarcane. The main problem with this product is the high cost of the associated decolourisation process for producing syrup with attractive colour for the consumer. This research project was conducted to study the effect of raw cane juice colour from different cane varieties on the colour of clear juice after purification and decolourisation steps as part of the process for the production of invert cane syrup. Purification of the raw cane juice was conducted using carbonatation-phosphatation followed by decolourisation of the clear juice using powder activated carbon (PAC). Sugarcane varieties were grouped into high, medium and low colour varieties having raw cane juice colour >20 000 IU, 10 000–20 000 IU and <10 000 IU, respectively. The correlation between raw cane juice colour and clear juice colour after the purification and decolourisation processes was very high. The colour of clear juice after purification followed by decolourisation using PAC at 1.6% on brix using high, medium and low colour cane varieties were 4500 IU, 2100 IU and 680 IU, respectively. In order to get the same colour as clear juice from low colour cane varieties, additional decolourisation processing was needed for clear juice from the high colour cane varieties. This investigation was able to show that using selective low colour sugarcane varieties in the production of invert cane syrup minimised the cost of decolourisation.

Introduction

Invert syrups are widely utilised by different segments of the food industry such as soft drink and baking industries due to their sweetness and specific physical-chemical properties. Recently, several efforts were conducted to develop a continuous process for making invert syrups from raw cane juice without crystallisation that was economical on a large scale (Serna-Saldivar and Rito-Palomares, 2005; Ginslov and Peter, 2000). Invert cane syrup produced using processes developed by Indonesian Sugar Research Institute (ISRI) still contains minerals and other non sugars such as amino acids and vitamins originating from the cane juice. The challenge of technologies for invert cane syrup production concerns juice purification and decolourisation processes to produce attractive colour in the clear cane syrup.

Several studies have been published on the changes of raw juice colour to the colour of clear juice after purification processes (Sharma et al., 1980; Sharma and Johary, 1984) and the changes of colour over each step of plantation white sugar production (Keskar and Nimbalkar, 1999). Johary and Singh (2001) reported on the effects of sugarcane varieties on juice colour. Of the varieties investigated, sugarcane variety CoS 91269 produced juice with the highest colour (12 985 units) compared with 5730 units for CoS 88230 variety, which produced the lowest coloured juice. Results of the study showed that, when the percentage of CoS 91269 variety in the total crop reduced from 47.55% to 37.33%, the colour of the sugar also decreased from 206.5 IU to 126.5 IU. These results show that the colour of raw juice depends on the variety and has a direct effect on the colour of sugar products.
This research project examined the possibility of minimising decolourisation costs of invert cane syrup production by using low colour cane varieties. The project investigated the effect of raw juice colour from different cane varieties on the colour of clear juice after purification and decolourisation steps as part of the process for the production of invert cane syrup.

Materials and methods

Laboratory experiments were conducted on the juice from various sugarcane varieties. The juices were purified with three different methods. Clear juices from the best purification method were decolorised using powder activated carbon (PAC). A pilot scale experiment was conducted only on the juice from the lowest colour cane variety using the best purification technique, followed by decolourisation using the optimum dose of PAC. The purpose of the pilot scale experiment was to check the consistency of the best result from the laboratory experiment using the larger scale process.

Laboratory experiments

Eight sugarcane varieties with various levels of juice colour were used in the laboratory stage experiments. The cane samples used in this experiment consisted of clean stalk without tops and trash. The cane was pressed twice using a small mill and the raw juice was collected for purification. Cane juice purification was conducted using three different methods namely simple phosphatation process (P); double carbonatation process (DC); and purification using a modified carbonatation-phosphatation process (DCP).

For the simple phosphatation process, raw cane juice was heated to 60°C and 400 ppm P₂O₅ (phosphoric acid) was added. Milk of lime at 5°Baumé was then added to raise the pH to 7 before the juice was heated to 100°C and then settled without flocculant addition. For the double carbonatation process, pH and temperature of the first carbonatation process were 10.5 and 55°C respectively. Milk of lime (8°Baumé) was used for the carbonatation process. The amount of lime milk added on raw juice was 10%(v/v). Raw juice was heated to 55°C and milk of lime was added until pH 10.5 was reached. The rest of the milk of lime was added to the juice during the addition of carbon dioxide to maintain the pH at 10.5. The temperature was kept constant at 55°C. After the reaction, the juice was filtered. Carbon dioxide was added to the filtered first carbonated juice to decrease the pH to 7.0, before the juice was further heated to 75°C and filtered. The purification process using the modified carbonatation-phosphatation process basically followed the double carbonatation process with phosphoric acid (27% v/v) added to the filtered first carbonated juice instead of carbon dioxide to reduce the pH to 7.0, before the juice was heated to 70°C and filtered. All filtration was conducted using filter paper (Whatman No.1). On the DCP process, kieselguhr was used as a precoat on the filter paper during the second filtration after the addition of phosphoric acid.

The clear juice from the purification processes were further decolourised using powder activated carbon (PAC) (analytical grade from Merck with an iodine adsorption value of 1220 mg/g) dosed at various concentrations. The mixture of clear juice and PAC was maintained at 70°C for one minute before it was filtered using Whatman No. 42 paper coated with kieselguhr.

Raw and clear juice samples were analysed for colour, brix (using refractometer), sucrose (measured by double polarisation), reducing sugar (Lane & Eynon method), CaO and MgO content (complexo-metric method), ash (conductivity) and turbidity.

Colour analysis of raw juice, clarified juice, and low colour juice after decolourisation using PAC was done by diluting the samples with distilled water to about 5, 10 or 15 brix or without dilution followed by method of ICUMSA GS1/3-7. The degree of sample dilution depended on the colour of the sample. The absorbance of the sample at 420 nm should be between 0.2 and 0.8. In the case of very low colour juice after decolourisation using PAC, there was no dilution needed for the sample. The turbidity on each juice was measured with a spectrophotometer at 900 nm using 50 mg
SiO₂ per litre of solution as a standard (Ananta and Martoyo, 1989). Raw juice was also analysed for phenolic content using the method described by Clarke et al. (1986) and the correlation between phenolic content and colour in raw juice was determined. The concentrations of CaO and MgO and phenolic content were calculated at 15 brix.

**Pilot scale experiments**

In the pilot plant experiments, cane juice from the lowest colour cane variety was purified using the combined carbonatation-phosphatation process (DCP) detailed above in a batch system. For one trial, 200 L of cane juice from around 400 kg of sugarcane (PS 862) was processed over four batches. Clear juice was decolorised using PAC at a dosage of 1.6% PAC on clear juice brix. The PAC used in the pilot scale experiments was industrial grade with an iodine adsorption value of 1100 mg/g. The clear juice after the PAC treatment was adjusted to pH 5 and evaporated at 70°C to syrup for analysis.

**Results and discussion**

**Laboratory experiments**

Table 1 shows the cane varieties used in this research project and grouped into high, medium and low colour. The varieties with the highest and the lowest colour were also included in Table 1 separately for comparison. The cane was harvested almost at the same maturation i.e. more than 20 brix with an average reducing sugar content of 3.56%.

Seven cane varieties used in this experiment were collected from the same area (Pasuruan Experiment Station). These varieties were grown in similar soils, under similar climatic conditions, and were also cultivated with the same technique. Hence, the various colours in the raw juice reflect the inherent properties of the different varieties. One variety (PS 862) was collected from the Jengkol area. The Jengkol area had land with more porous and better drainage characteristics for good growth of the PS 862 cane and differed from the land characteristics in the Pasuruan area (compact soils and poor drainage).

<table>
<thead>
<tr>
<th>Group</th>
<th>Sugarcane varieties</th>
<th>Brix</th>
<th>Sucrose purity (%)</th>
<th>Reducing sugar (% on Brix)</th>
<th>Colour of raw cane juice (IU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest colour</td>
<td>PS 921</td>
<td>21.9</td>
<td>91.12</td>
<td>1.28</td>
<td>42 384</td>
</tr>
<tr>
<td>High colour</td>
<td>PS 891, PS 851, PS 921, PSJT 9344</td>
<td>20.72 ± 1.2</td>
<td>87.42 ± 4.11</td>
<td>3.73 ± 2.45</td>
<td>31 380 ± 5500</td>
</tr>
<tr>
<td>Medium colour</td>
<td>PS 864, PS 97226</td>
<td>21.14 ± 0.7</td>
<td>86.74 ± 1.4</td>
<td>3.47 ± 0.45</td>
<td>16 756 ± 2105</td>
</tr>
<tr>
<td>Low colour</td>
<td>PS 951, PS 862</td>
<td>21.50 ± 0.8</td>
<td>89.81 ± 0.18</td>
<td>3.48 ± 0.28</td>
<td>8357 ± 1153</td>
</tr>
<tr>
<td>Lowest colour</td>
<td>PS 862</td>
<td>21.54</td>
<td>89.63</td>
<td>3.76</td>
<td>7289</td>
</tr>
</tbody>
</table>

Raw cane juice from each cane variety was purified using the three different processes (P), (DC) and (DCP). These three purification techniques were chosen with consideration that the clear juice resulting from these processes will be safe for direct consumption. Other purification processes such as sulfitation were not selected because the residual SO₂ in the clear juice was considered harmful to human health.

Table 2 shows the performance of the three clarification processes averaged for all cane varieties. The DCP purification process produced the best results in terms of high purities, low residual calcium and magnesium ions (CaO+MgO) and low turbidity, followed by the DC and P processes. The improvement in sucrose purity for purification using DCP, DC and P were 3.21, 2.98 and 1.05 units respectively and the reduction of CaO+MgO content were 27.6, 22.2 and 39.9% for
the DCP, DC and P processes respectively. Clear juice with low turbidity values resulted from the DC and DCP purification processes.

Table 2—Effect of purification process using phosphatation (P), double carbonatation (DC) and combination of double carbonatation+phosphatation process (DCP) on sucrose purity, CaO+MgO and turbidity.

<table>
<thead>
<tr>
<th>Purification process</th>
<th>Sucrose purity (%)</th>
<th>CaO+MgO (ppm in juice at 15 brix)</th>
<th>Turbidity (ppm SiO2 in juice at 15 brix)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before purification</td>
<td>87.85 ± 3.67</td>
<td>742 ± 124</td>
<td>1156 ± 298</td>
</tr>
<tr>
<td>Phosphatation</td>
<td>88.90 ± 3.75</td>
<td>537 ± 176</td>
<td>16 ± 10</td>
</tr>
<tr>
<td>Double carbonatation</td>
<td>90.83 ± 2.90</td>
<td>577 ± 120</td>
<td>10 ± 7</td>
</tr>
<tr>
<td>Double carbonatation+phosphatation</td>
<td>91.06 ± 2.16</td>
<td>446 ± 144</td>
<td>7 ± 10</td>
</tr>
</tbody>
</table>

The changes in colour during each purification process are shown in detail for each group of cane varieties in Figure 1. The results show that the average decrease in colour of the juice from all groups of sugarcane varieties after purification using P, DC and DCP were 14.4, 56.6 and 71.7% respectively. The best colour removal resulted from purification using DCP. A review by Sharma and Johary (1984) indicated that removal of colorants during purification of cane juice took place either by way of precipitation / coagulation or through adsorption on the surface of various precipitates produced during the clarification process. Previous experiments conducted by Sharma et al. (1980) and Sharma and Johary (1984) support the results of this research in that the mud produced during the carbonatation process could adsorb larger magnitudes of colorants as compared to sulfitation and defecation processes. The juice purification process trialed in this research based on simple phosphatation (P) was basically similar to the defecation process with the addition of phosphoric acid (400 ppm P2O5).

![Fig. 1—Changes in juice colour after purification using phosphatation (P), double carbonatation (DC) and a combination of double carbonatation+phosphatation process (DCP) for each group of cane varieties.](image-url)
The laboratory trials clearly showed that the clear juice colour was significantly influenced by the colour of the raw juice. The trials showed that higher raw juice colour resulted in the highest clear juice colour after the purification processes. The clear juice colour from simple purification using P process of the low colour group of cane varieties was similar to the clear juice colour resulting from the high colour group of cane varieties using more complex purification techniques like DCP.

One of the major colorant groups in the cane plant is the phenolic compounds (Clarke et al., 1986). Figure 2 shows the correlation between the colour of raw juice and the phenolic content calculated for each juice at 15 brix. Higher raw juice colours correlated with a higher content of phenolic compounds. The correlation $R^2$ value was 0.77.

![Graph showing correlation between colour of raw cane juice and the phenolic content.]

The clear juice resulting from the DCP purification process was further decolorised using various concentrations of PAC including 0; 0.1; 0.2; 0.8; 1.6; 3.2 and 6.4% on clear juice brix (see Figure 3). The results showed that the colour of clear juice after decolourisation using PAC was influenced by the colour of the clear juice before PAC treatment. The colour of the clear juice after decolourisation using PAC was influenced by the colour of raw juice before the purification process. The magnitude of the colour reduction declined as the concentration of PAC was increased. The lowest colour juice (from cane variety PS 862) reached a minimum value when the PAC reached 1.6% on juice brix. These results showed that not all of the colour could be removed using PAC.

![Graph showing the effect of PAC dose on the colour of clear juice.]

Fig. 3—Clear juice colour from purification using the double carbonatation+ phosphatation process followed by decolourisation using various concentrations of PAC.
Figure 4 shows the colour of clear juice from each group of cane varieties after purification using the DCP process followed by decolourisation using PAC at a dosage of 1.6% on clear juice brix. The colour of clear juice after purification by the DCP process followed by decolourisation using PAC at 1.6% on brix for the high, medium and low colour varieties were 4500 IU, 2100 IU and 680 IU, respectively. In order to get the same colour as clear juice from low colour varieties, additional decolourisation (or higher dosage of PAC as shown in Figure 3) would be required for the clear juice from high colour varieties. This result showed that the cost of decolourisation on invert cane syrup production was able to be minimised using low colour sugarcane varieties.

![Graph showing the average colour of clear juice from each group of cane varieties.](image)

**Fig. 4**—Average colour of clear juice from each group of cane varieties after purification using the DCP process followed by decolourisation using PAC at 1.6% on clear juice brix.

Purification of the lowest colour cane varieties with the DCP process followed by decolourisation using PAC at 1.6% on clear juice brix was further tested in pilot scale trials as part of the process for invert cane syrup production.

**Pilot scale experiments**

The analysis of cane juice over each step of the DCP clarification process, decolourisation and evaporation to produce cane syrup is shown in Table 3. The data are the average of eight trials. Around 400 kg of cane was processed for each trial. The results showed that the average brix of raw juice was 21.1, purity 87.7%, reducing sugar 4.95%, CaO+MgO 372 ppm and colour 9865 IU. The quality of raw juice used in the pilot scale experiments was similar to that of the laboratory experiments. The purification process resulted in the juice purity increasing by 1.36 units, colour decreasing by 70.7%, while the reducing sugar and ash conductivity (% on brix) were almost constant.

After the purification process the clear juice was decolourised using PAC at 1.6% on clear juice brix. The decolourisation step decreased the clear juice colour by 74.6% (average 738 IU). The clear juice was then evaporated. There was a slight increase in colour after evaporation from 737 IU to 991 IU and the thick juice was still very clear with just a slight increase in turbidity.

The low colour thick juice will be used to produce invert cane syrup through sucrose inversion with a final decolourisation step. Sucrose inversion using immobilised invertase is being developed by ISRI. The final decolourisation step on invert cane syrup production uses weak anionic or strong anionic resin regenerated using disodium hydrogen phosphate (Triantarti and Toharisman, 2008).
Table 3—Results of cane juice analyses following clarification using the DCP process, decolourisation using PAC and evaporation.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Raw cane juice</th>
<th>Clear juice after purification with DCP</th>
<th>Clear juice after purification with DCP and Decolourisation using PAC</th>
<th>Thick juice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brix</td>
<td>21.09 ±0.67</td>
<td>14.98 ± 1.35</td>
<td>14.03 ± 1.09</td>
<td>74.01 ± 2.23</td>
</tr>
<tr>
<td>Sucrose (%)</td>
<td>18.50 ±0.84</td>
<td>13.33 ± 1.14</td>
<td>12.55 ± 0.87</td>
<td>66.44 ± 2.64</td>
</tr>
<tr>
<td>Purity (%)</td>
<td>87.66 ± 2.12</td>
<td>89.02 ± 1.82</td>
<td>89.47 ± 1.95</td>
<td>89.75 ± 1.09</td>
</tr>
<tr>
<td>Reducing sugar (%)</td>
<td>4.95 ± 1.24</td>
<td>4.36 ± 0.93</td>
<td>4.55 ± 0.89</td>
<td>4.19 ± 0.99</td>
</tr>
<tr>
<td>Colour (IU)</td>
<td>9665 ± 2.109</td>
<td>2890 ± 585</td>
<td>738 ± 250</td>
<td>991± 539</td>
</tr>
<tr>
<td>CaO+MgO in juice at 15 brix (ppm)</td>
<td>372 ± 144</td>
<td>368 ± 140</td>
<td>369 ± 140</td>
<td>202 + 70</td>
</tr>
<tr>
<td>Ash conductivity (% on brix)</td>
<td>1.24 ± 0.13</td>
<td>1.31± 0.31</td>
<td>1.39 ± 0.33</td>
<td>1.02 ± 0.11</td>
</tr>
<tr>
<td>Turbidity at 15 brix (ppm SiO₂)</td>
<td>547 ± 36</td>
<td>18 ± 4</td>
<td>4 ± 2</td>
<td>9 ± 6 *</td>
</tr>
</tbody>
</table>

Note: Turbidity was calculated for juice at 60 brix.

The result of the pilot scale experiment using the lowest colour cane variety (PS 862) showed a consistent result on low colour of clear juice compared with the laboratory result using the same cane variety, purification process and decolourisation process. The results of both laboratory and pilot scale experiments showed that minimising decolourisation costs of invert cane syrup production by using low colour cane varieties was quite promising.

However, the colour of raw juice not only depends on the cane variety but also on many factors such as agro-climatic conditions prevailing during the growth period, land characteristics and cultivation techniques. Before commercial scale production of invert cane syrup can commence, several trials have to be done by planting low colour cane varieties in different areas that will be cultivated and processed to determine the quality of raw juice produced (especially colour). The colour of raw juice is also influenced by the sugarcane maturation during harvesting, time between harvesting and milling and the cleanliness of the cane based on included dirt, tops and trash (Sens and Decagny, 2001). Good management of cane cultivation, harvesting and post harvest practices are very important to get a consistent, good quality sugarcane that produces low colour raw juice.

Conclusions

Cane juice purification using a combination of double carbonatation and phosphatation processes provided the best quality juice (low colour, high purity) that can be used for invert cane syrup production. The colour of clear juice after purification and decolourisation using PAC is influenced by the colour of the raw juice. In the pilot scale experiments, the colour of thick juice produced using low colour cane varieties after purification using double carbonatation and phosphatation processes, followed by decolourisation using PAC at dosage 1.6% on brix of clear juice, reached 991 IU. However, further research is needed to determine cane cultivation conditions which affect the colour of cane juice especially for potential low colour cane varieties.

REFERENCES


Réduction du coût de décoloration de sirops invertis grace a des variétés de canne de couleur faible

Par

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Mots-clefs : Couleur, Canne a Sucre, Variété, Purification, Décoloration.

Résumé

La production de sirop de canne à sucre inverti est un produit de diversification de la canne. Le principal problème avec ce produit est le coût élevé du processus de décoloration, pour la production d’un sirop avec une couleur attrayante pour le consommateur. Cette recherche a été réalisée pour étudier l'effet de la couleur du jus de canne provenant de différentes variétés sur la couleur du jus clair après les étapes de purification et de décoloration pendant la production de sirop de canne à sucre inverti. La purification du jus de canne brut a été menée à l'aide de la carbonatation-phosphatation suivie de décoloration du jus clair à l'aide de charbon actif en poudre (PAC). Les variétés ont été regroupées en couleur de jus haute, moyenne et faible, dans des fourchettes > 20 000 UI, 10 000 à 20 000 UI et 10 000 UI, respectivement. La corrélation entre la couleur de jus de canne brut et la couleur de jus clair après les processus de purification et de décoloration était très élevée. Les couleurs du jus clair après purification suivie de décoloration à l'aide du PAC (consommation 1.6% sur brix) pour les variétés de couleur haute, moyenne et basse ont été IU 4500, IU 2100 et 680 UI, respectivement. Afin d'obtenir la couleur de jus clair provenant de variétés a faible couleur, une décoloration supplémentaire était nécessaire pour les jus clair obtenus a partir des variétés de couleur haute. Ce travail a pu démontrer que l'utilisation de variétés a couleur faible pour la production de sirop de canne à sucre inverti réduit au minimum le coût de la décoloration.
MINIMIZACIÓN DEL COSTO DE DECOLORACIÓN DE JARABE INVERTIDO USANDO VARIEDADES DE CAÑA DE BAJO COLOR

Por

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PALABRAS CLAVE: Color, Caña, Variedad, Purificación, Decoloración.

Resumen

LA PRODUCCIÓN de jarabe invertido de caña es una alternativa de diversificación de productos. El problema principal es el alto costo de los procesos de decoloración para obtener un producto atractivo al consumidor. Esta investigación fue orientada al estudio del efecto del color del jugo de diferentes variedades de caña en el color del jugo clarificado después de las etapas de purificación y decoloración como parte del proceso de obtención de jarabe invertido. La purificación se efectuó usando carbonatación- fosfatación seguida de decoloración del jugo claro usando carbón activado en polvo (PAC). Las variedades de caña se agruparon en bajo, medio y alto color con colores en jugo crudo de >20000 IU, 10000–20000 IU and <10000 IU, respectivamente. La correlación entre color de jugo crudo y color de jugo claro, después de los procesos de purificación y decoloración fue alta. El color del jugo claro después de purificación seguida de decoloración usando PAC a 1.6% en brix y usando variedades de alto medio y bajo color fue de 4500 IU, 2100 IU y 680 IU, respectivamente. Para obtener el mismo color del jugo claro obtenido a partir de variedades de bajo color, se requirió procesamiento adicional de decoloración con las variedades de alto color. La investigación mostró que el uso de variedades de bajo color en la producción de jarabe invertido, minimiza los costos de decoloración.
ENERGY CONTENT: A NEW APPROACH TO CANE EVALUATION

By

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KEYWORDS: Energy, Coproducts, Fibre, Cogeneration, Quality.

Abstract

In recent years, the sugarcane industry has been moving from sugar production alone to sugar and energy production with the development of cogeneration and ethanol plants. Although cane fibre has always been considered a problem by the sugar millers, with increasing energy prices, fibre is becoming a major co-product of cane. The energy balance between sugar losses and energy production was evaluated for conventional cane and a new high fibre cane. The energy content of cane and cane products was calculated using their net calorific values. The results show that sugar is the main energy product recovered. Depending on their different uses, varietal comparisons based on energy content could be a new way of comparing sugarcane varieties. In Reunion Island, where cogeneration started in 1992, upcoming changes in French law on carbon credits are likely to modify the price of fibre for energy production in 2009. These changes will lead to the release of new cane varieties for sugar and electricity production, such as the promising eRcane elite cane R92/0804. A new approach to cane evaluation can therefore be based on the energy content of cane.

Introduction

The energy content of sugarcane offers a new approach to cane evaluation. Sugarcane bagasse is now regarded as ‘bioenergy’ and its value can be compared to that of coal. However, to fully exploit the value of bagasse, it is important to change strategies from sugar production alone to sugar and energy production.

This will lead to major changes in the sugarcane industry, such as grower payments for sugar and for fibre, and new varieties with higher levels of sugar and fibre. Cane energy content and energy yield per hectare and per tonne of cane will therefore become important parameters (Botha, 2009). Cane varieties should therefore be optimised for maximum energy production (Lima Verde Leal, 2007).

A new cane variety (R92/0804) that combines high fibre and sugar content has been developed in Reunion Island by eRcane. This variety was crossed (R575 × H72/8597) in 1992 and is now at the end of the breeding program. Agronomical results of five regional trials based on plant cane and two ratoons are presented in Table 1.

The two main varieties cultivated in Reunion, R570 (released in 1978) and R579 (released in 1993), were used as standards for the trials. Compared to the R579 standard, R92/0804 clearly gave better yields (+44%) with slightly lower sugar content in the cane (−3.6%) but a 29% increase in fibre content. Therefore, the overall increase in sugar yield per hectare is around 30%. This new variety appears to be promising in terms of tonnes of sugar per hectare, but the high fibre content should also be taken into account from the millers’ point of view.
The objective was to add an indication of potential energy production to the traditional agronomic comparisons based on sugar yield per hectare. This potential energy production should be linked to the total energy content of cane, which can be divided into three elements: energy in fibre, energy in ethanol and energy in sugar crystals. This study was undertaken to assess the impact of different varieties on the energy recovered in terms of electricity, ethanol and sugar.

**Calculation methodology based on net calorific value of products**

This case is an example of what can be done on the basis of energy content in a country such as Reunion Island, with cane that mainly produces sugar, but also cogenerates electricity and produces rum from molasses.

The energy content of sugarcane and cane products was calculated using net calorific value. Net calorific value (NCV) is more practical than gross calorific value because it does not take into account the latent heat of the vapour. The NCV can be calculated from the chemical reaction on combustion.

The NCV of the sugarcane was calculated as the sum of the net calorific values of fibre, sucrose, glucose and fructose. The net calorific value of the cane fibre was calculated from a bagasse equivalent energy: bagasse weight as twice the cane fibre content and bagasse net calorific value of 4.23 kWh/kg (assumptions made for bagasse composition were 50% moisture, 1.2% ash content and 2.6 brix) with the SASTA Laboratory Manual (Anon, 2005).

The net calorific values of reducing sugars (glucose and fructose), ethanol and sucrose were 3.17, 6.20 and 3.56 kWh/kg respectively.

**Cane and cane product energy content**

Traditional agronomic comparisons of sugarcane are based on extractable sucrose. A simple method for estimating extractable sucrose is to deduct the sugar in the bagasse and the molasses from the sugar in the cane; mud and undetermined losses are not taken into account.

\[
\text{Extractable sugar} = \text{Sugar in cane} - \text{Sugar in bagasse} - \text{Sugar in molasses}
\]

Net calorific value was used to convert the weight of bagasse, ethanol and extractable sugar into energy.

**Net energy content of sugarcane in Reunion Island conditions**

The energy content of cane was calculated according to the fibre, reducing sugars and sucrose contents from the agronomic trials (Table 2).

<table>
<thead>
<tr>
<th>Table 2—Net energy content of sugarcane in Reunion Island conditions.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net energy content of cane</td>
</tr>
<tr>
<td>R570</td>
</tr>
<tr>
<td>R579</td>
</tr>
<tr>
<td>R92/0804</td>
</tr>
</tbody>
</table>
Fibre in cane increases bagasse losses but also electricity production

Bagasse weight is directly affected by the fibre content of the cane and by bagasse moisture. Pol in bagasse is assumed to be a result of the milling operation. In sugar mills, sugar losses in bagasse are calculated using the following equation:

\[
\text{Sugar lost in bagasse} = \frac{\text{Sugar in bagasse}}{\text{Bagasse weight}} \times \text{pol\%bagasse}
\]

It can be assumed that, with satisfactory milling operations, bagasse moisture and pol in bagasse can be maintained respectively at 50% and 1%. Hence, the previous equation can be simplified to:

\[
\text{Sugar lost in bagasse} = \frac{\text{Fibre\%cane}}{50\%} \times 1\%
\]

\[
\text{Sugar lost in bagasse} = 2\% \times \text{Fibre\%cane}
\]

This assumption oversimplifies reality but can be used as an easy method. Therefore, with an increase of cane fibre content, sugar lost in bagasse will increase as indicated in Table 3.

Energy from electrical production with bagasse can be estimated with the power delivered by the cogeneration plant to the electrical network.

Cogeneration and power production has been carried out in Reunion Island since the first installation of 80 bar boilers at Bois Rouge Mill in 1992. The cogeneration plants at the two factories in Reunion have two 30 MW turbines in Bois Rouge and two 32 MW turbines in Le Gol. Electricity produced with bagasse in Reunion has a ratio of 0.52 MWh/tonne of wet bagasse (ARER, 2008).

This ratio takes into account sugar mill steam and electrical power consumption. Based on cane fibre content, electricity production can be estimated using this ratio as indicated in Table 3.

| Table 3—Fibre in cane increases bagasse losses but also electricity production (For bagasse pol = 1% and bagasse moisture = 50%). |
|---|---|---|---|
| R570 | Fibre in cane % cane 16.52 | Sugar in bagasse % cane 0.33 | Electricity Production KWh/t cane 172 |
| R579 | 14.77 | 0.30 | 154 |
| R92/0804 | 19.02 | 0.38 | 198 |

Sugar in molasses increases losses in molasses but also ethanol production

The sugar content in molasses can be estimated using the SJM formula with a molasses standard purity of 40 (Table 4).

The total fermentable sugar content was calculated with the results of sugar content in molasses and with an average reducing sugar content in molasses of 7.7% (Reunion average for 2008 crops).

This total fermentable sugar content can be used to estimate ethanol production based on Pasteur Yield (643 L of alcohol / tonne of sucrose) and average distillery performance (86%) as presented in the equation below. Ethanol was converted into kWh with density data (0.791 kg/L) and net calorific value.

\[
\text{Ethanol yield (L/100 t cane)} = \text{Molasses\%Cane} \times \text{Total fermentable sugar\%molasses} \times 643 \times 86\
\]

Ethanol production does not appear to be affected by variety (Table 4). Varietal comparison based on ethanol yield in L/100 t cane or in kWh/t cane is close for the three varieties tested.
Table 4—Sugar in molasses increases losses in molasses but also increases ethanol production (% cane = tonnes sugar/100 tonnes of cane).

<table>
<thead>
<tr>
<th>Sugar in molasses</th>
<th>Ethanol production</th>
</tr>
</thead>
<tbody>
<tr>
<td>% cane</td>
<td>L/100 t cane</td>
</tr>
<tr>
<td>R570</td>
<td>1.01</td>
</tr>
<tr>
<td>R579</td>
<td>1.02</td>
</tr>
<tr>
<td>R92/0804</td>
<td>1.06</td>
</tr>
</tbody>
</table>

Extractable sugar can be converted into energy

The extractable sugar can be calculated from the sugar in cane minus bagasse losses minus sugar in molasses. This extractable sugar can be converted into energy content with the sucrose, glucose and fructose net calorific values, as presented in Table 5. In these trials, R92/0804 has the lowest level of extractable sugar but, due to the high yield per hectare, sugar production is increased by 32%.

Table 5—Extractable sugar is energy (% cane = tonnes sugar/100 tonnes of cane).

<table>
<thead>
<tr>
<th>Extractable sugar</th>
<th>Extractable sugar</th>
</tr>
</thead>
<tbody>
<tr>
<td>% cane</td>
<td>kWh/t cane</td>
</tr>
<tr>
<td>R570</td>
<td>11.66</td>
</tr>
<tr>
<td>R579</td>
<td>11.77</td>
</tr>
<tr>
<td>R92/0804</td>
<td>11.16</td>
</tr>
</tbody>
</table>

Energy based varietal comparison

Energy based varietal comparisons can be made using the net energy content of the cane and the energy recovered in electrical production, ethanol and in sugar crystals.

Results show that sugar is the main energy product recovered (35%) from sugarcane (Figure 1). Energy recovered in electricity and ethanol represents respectively around 15% and 3% of the energy content of the cane.
Results per hectare also show that sugar is the main energy product recovered from sugarcane (Figure 2). According to the agronomic results presented in Table 1, R92/0804 has 34.6% higher yields than R570 and R579 and this leads to greater differences in terms of cane energy content and energy recovered in the different products.

![Figure 2—Varietal comparison based on energy content per hectare.](image)

Current process efficiencies lead to high energy losses between cane energy content and energy recovered. The total energy recovered for R570, R579 and R92/0804 is 50, 52 and 47% respectively.

There are clearly varietal differences and R92/0804 has the highest potential for electrical, ethanol and sugar production compared to the two other varieties. R570 and R579 have the same net energy content per hectare, but R570 appears to produce more electricity and less sugar compared to R579.

A possible limitation of this paper stems from the assumptions made for the calculations (extractable sugar, ethanol and cogeneration yields). The figures could also be completed with data on energy consumption during processing, which varies depending on cane composition.

This new approach to cane energy content highlights that sugar is the main energy component of sugarcane. A practical application for breeders is to develop new selection schemes to increase fibre and sugar content. As for millers, depending on energy prices, the traditional sugar losses can now be seen in terms of energy and economic gains.

**Conclusions**

This new approach to cane evaluation based on cane energy content highlights that sugar is the main energy component of sugarcane. All the parameters presented in this paper can be used on a large scale to compare different cane varieties using existing parameters. Future improvements call for the development of new parameters to replace the different theoretical ratios used at present. All the theoretical assumptions must be proved experimentally and measured in order to assess the overall impact of high fibre cane on sugar processing.

These preliminary results show that R92/0804 can increase the overall energy content, which will result in an increase in sugar and electricity production. Sugar processing is likely to be affected with an increase in sugar losses.

In Reunion Island, the sugarcane industry is moving forward. Bagasse now has value, which
will be paid to the growers for the 2009 crop. The exact payment method is still under study, but it is a sign that sugarcane will no longer be cultivated for sugar alone. This new value will be a complement to the sugar value, which is still the main energy component of cane.

When new varieties with higher levels of sugar and fibre are released, this will have an impact on sugar mills’ performance. Further research is required to evaluate this impact.

Acknowledgment

Special thanks to Henri Piras and William Hoareau for their contribution to this paper.

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CONTENU ENERGETIQUE: UNE NOUVELLE APPROCHE POUR L'EVALUATION DE LA CANNE

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MOTS CLÉS: Énergie, Coproduits, Fibre, Cogénération, Qualité.

Résumé

DEPUIS plusieurs années, l’industrie cannière a évolué d’une extraction du sucre à du sucre et une production énergétique avec le développement de la cogénération et des distilleries d’éthanol. La fibre de la canne a toujours été considérée comme un problème par l’industriel sucrier. Avec l’augmentation du prix de l’électricité, la fibre devient un coproduit majeur de la canne. La balance de l’impact de la fibre sur les pertes en sucre et la production énergétique a été évaluée. Ce document compare les impacts des cannes à forte fibre sur les procédés sur une base de bilan énergétique. Selon les débouchés, la comparaison variétale sur des bases énergétiques peut être une nouvelle façon de sélectionner des cannes. À La Réunion, la cogénération a débuté en 1992 et les futurs changements liés aux lois françaises et aux crédits carbone vont modifier le prix de l’énergie en 2009. Ces changements vont conduire à libérer des nouvelles variétés pour la production sucrière et électrique comme l’élite promise d’eRcane la R92/0804. Une nouvelle approche pour l’évaluation des cannes peut être basée sur le contenu énergétique de la canne. Le contenu énergétique de la canne et de ses coproduits à été calculé en utilisant leur pouvoir calorifique inférieur.
CONTENIDO DE ENERGÍA: UN NUEVO ENFOQUE PARA LA EVALUACIÓN DE LA CAÑA

Por

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PALABRAS CLAVE: Energía, Co-Productos, Fibra, Cogeneración, Calidad.

Resumen
EN AÑOS recientes, la industria de la caña de azúcar se ha estado moviendo de la producción de azúcar únicamente, a la producción de azúcar y energía con el desarrollo de la cogeneración y las plantas de etanol. Aunque la fibra en caña ha sido siempre considerada un problema por los operadores de molienda, con los precios crecientes de la energía la fibra se está convirtiendo en un co-producto principal de la caña. El balance de energía entre pérdidas de sacarosa y producción de energía fue evaluado para caña convencional y nuevas cañas altas en fibra. El contenido de energía de la caña y sus productos fue calculado usando sus valores caloríficos netos. Los resultados mostraron que el azúcar es el principal producto energético recuperado. Dependiendo de sus diferentes usos, las comparaciones varietales basadas en su contenido energético podrían ser una nueva forma de comparar variedades de caña. En la isla Reunión, donde la cogeneración inició en 1992, se avecinan cambios en la ley francesa sobre créditos de carbono que podrían modificar el precio de la fibra para producción de energía en 2009. Estos cambios llevarán a la liberación de nuevas variedades de caña para azúcar y para producción de energía, como la promisoria variedad de élite R92/0804. Un nuevo enfoque para la evaluación de variedades podría estar basado en el contenido energético de la caña.
POLARISATION BY FILTRATION FOR CANE PAYMENT AND FACTORY CONTROL

By

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KEYWORDS: Cane Quality, Analysis, Pol, Lead, Filtration.

Abstract

LABORATORY analyses are used worldwide to assess the quality of sugarcane and sugar processing products. Polarimetry is the basic sucrose analysis in the laboratory to assess sugarcane quality and factory performance. Pol measurement requires a clarification step that is usually carried out with lead subacetate. A non-lead method has been developed based on filtration. This filtration method has been assessed for its suitability for cane analysis for payment purposes and for factory products (mixed juice, bagasse, mud and molasses) for process control. Results for pol in cane are on average 0.08% lower with the filtration method than with the standard lead clarification method. Results for factory control show that apparent sucrose entering the mill decreases by 0.08, resulting in an equivalent decrease in undetermined losses. To conclude, polarisation by filtration is suitable for cane payment and factory control and is now used in Reunion Island for these purposes.

Introduction

For many years, the world sugar industry has used laboratory measurements to improve its efficiency, carrying out analyses on sugarcane and on sugar processing products. The analyses of sugarcane are needed to measure cane quality for agronomic and commercial purposes, whereas the analyses on sugar processing products are needed to measure factory balances and sugar losses in the mills and to improve sugar recovery. All the cane analysis methods use polarisation to estimate sucrose as it is an accurate, simple and economical method.

In the past, the polarisation method used lead subacetate but, with the increasing recognition of environmental and health factors, new methods have recently been developed employing other chemicals (Altenburg and Chou, 1991) or using filtration (Hoareau et al., 2008). Lead clarification produces juice with low colour and a polarimeter with a visible wavelength (from 587 to 589.44 nm, pol589) can be used. Filtration does not remove colour and an infrared wavelength (825 to 882.60 nm, pol882) polarimeter therefore has to be used.

In many countries, the sugar content in cane is measured for payment purposes. In Reunion Island, the Centre Technique Interprofessionnel de la Canne à Sucre (CTICS) is responsible for cane analysis for cane payment. The analysis is based on core sampling of each load followed by cane analysis by the press method. Methodological differences should be taken in account to maintain the economic balance between growers and millers. The first trials on non-lead pol started at the end of the 1990s and methods were developed in collaboration with eRcane.

This paper compares results by lead clarification pol (pol589) with filtration pol (pol882) for cane payment systems and factory control.
Materials and methods

Polarisation method for cane payment

Pol measurement

Lead clarification pol (pol_{589}) was carried out on pressed juice using lead subacetate (1.5 g / 250 mL) followed by gravity filtration with Fioroni 1591 filter paper.

Filtration pol (pol_{882}) was carried out on pressed juice using a filter aid (8 g of Clarcel CBL) followed by pressure filtration (Schmidt and Haensch Autofilt) with Fioroni 1105A filter paper. The pol and brix were measured on the same filtrate sample.

An REI Polaser SRC64 polarimeter (825 nm wavelength) was used for cane analysis at CTICS.

Pol in pressed juice with lead or by filtration was used to calculate pol in cane, according to the CTICS protocol (2009).

Cane sampling

Cane analysis by the press method is used for payment purposes in Reunion Island. Experiments were carried out at CTICS during the 2007 and 2008 crushing seasons when 4537 and 6439 samples were collected respectively to compare pol_{589} and pol_{882}. The trials were performed in five delivery stations in different parts of the island (Figure 1).

Fig. 1—Map of CTICS delivery stations in Reunion Island (trials in brown shaded sites).

Polarisation method for factory control

Pol measurement

Lead clarification pol (pol_{589}) was carried out on factory products using lead subacetate (Table 1) followed by gravity filtration with Fioroni 1591 filter paper.

Table 1—Lead clarification pol method for factory products (ARTAS, 1992; ICUMSA, 1994)

<table>
<thead>
<tr>
<th>Product</th>
<th>Dilution</th>
<th>Lead weight (g/250 mL)</th>
<th>Polarimeter tube length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane</td>
<td>–</td>
<td>3.75</td>
<td>100</td>
</tr>
<tr>
<td>Mixed juice</td>
<td>–</td>
<td>2.5</td>
<td>200</td>
</tr>
<tr>
<td>Final molasses</td>
<td>1/6 (w/w) follow by 13/100 (w/V)</td>
<td>13</td>
<td>200</td>
</tr>
<tr>
<td>Mud</td>
<td>72 / 500 (w/V)</td>
<td>0.4</td>
<td>200</td>
</tr>
<tr>
<td>Bagasse</td>
<td>250 g + 2500 g</td>
<td>0.2</td>
<td>200</td>
</tr>
</tbody>
</table>
Filtration pol (pol$_{882}$) was carried out on pressed juice using a filter aid (Table 2) followed by pressure filtration (Schmidt and Haensch Autofilt) with Fioroni 1105A filter paper.

<table>
<thead>
<tr>
<th>Product</th>
<th>Dilution</th>
<th>Clarcel CBL weight (g/200 mL)</th>
<th>Polarimeter tube length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane</td>
<td>–</td>
<td>8</td>
<td>100</td>
</tr>
<tr>
<td>Mixed Juice</td>
<td>–</td>
<td>15</td>
<td>100</td>
</tr>
<tr>
<td>Final molasses</td>
<td>1 / 20 (w/w)</td>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td>Mud</td>
<td>72 g + 500 mL</td>
<td>5</td>
<td>100</td>
</tr>
<tr>
<td>Bagasse</td>
<td>250 g + 2500 g</td>
<td>5</td>
<td>100</td>
</tr>
</tbody>
</table>

A Schmidt & Haensch Polartronic NIR W2 dual wavelength (589.44 nm and 882.6 nm) polarimeter was used for all factory products.

**Sucrose analysis by HPLC and HPAEC-PAD**

Sucrose in juice and molasses was analysed by HPLC (ICUMSA, 2002) and by HPAEC-PAD for mud and bagasse (ICUMSA, 1998). Hoareau et al. (2010) present further details of these methods.

As the lead concentration in the filtrate was around 3.8 g/L, the juice was filtered through an OnGuard II H Cartridge (Dionex) to avoid column damage.

**Factory product sampling**

Experiments on mixed juice and molasses were conducted in the 2001, 2002, 2006 and 2008 crushing seasons with weekly composite samples from the Le Gol and Bois-Rouge factories. These samples were analysed for pol$_{589}$, pol$_{882}$ and sucrose. Bagasse and mud were analysed during the 2008 crushing season.

Statistical analyses have been done with R Development Core Team software (R Development Core Team, 2009).

**Filtration pol is suitable for cane payment**

**Pol by filtration is lower than pol with lead clarification**

Results show that pol by filtration is suitable for measuring pol in cane. During the 2008 crop, 6439 analyses were compared for pol$_{589}$ and pol$_{882}$. A strong correlation was found between the two methods (Figure 2). The regression coefficient is highly significantly different from zero (p value<2.2 $10^{-16}$).

![Fig. 2—Pol in cane measured with lead clarification and with filtration (2008 results).](image-url)
The results of filtration pol are 0.08 lower on average than lead clarification pol (Table 3). The same trials conducted in 2007 showed a difference of 0.07. This average difference takes into account the results of the trials in the five delivery stations. In individual delivery stations, the average differences ranged from 0.06 to 0.13. The sugarcane tonnages delivered to the five delivery stations were used to calculate the 0.08 weighted average.

Table 3—Average differences between filtration pol (pol882) and lead clarification pol (pol589) for the 2007 and 2008 crushing seasons.

<table>
<thead>
<tr>
<th>Delivery station</th>
<th>2007</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beaufond</td>
<td>-0.07</td>
<td>-0.13</td>
</tr>
<tr>
<td>Bois-Rouge</td>
<td>-0.04</td>
<td>-0.08</td>
</tr>
<tr>
<td>Grand-Pourpier</td>
<td>-0.14</td>
<td>-0.13</td>
</tr>
<tr>
<td>Le Gol</td>
<td>-0.08</td>
<td>-0.06</td>
</tr>
<tr>
<td>Casernes</td>
<td>-0.11</td>
<td>-0.07</td>
</tr>
<tr>
<td>Weighted average</td>
<td>-0.07</td>
<td>-0.08</td>
</tr>
</tbody>
</table>

Filtration pol is now used in Reunion Island for cane payment. From the results in Table 3, there is a statistically significant difference between the two methods (p value=0.0004).

The payment system had to be modified to maintain the economic balance between growers and millers. It has therefore been adjusted with a correction factor of 0.075 that is the average difference between the two years of testing. The new payment system uses the following formula:

\[
\text{Pol \% Cane} = \text{Pol}_{882} \% \text{ Cane} + 0.075
\]

**Explanation of differences between pol by filtration and by lead clarification**

The differences measured between lead clarification and filtration pol can be explained by the removal of glucose and fructose by lead. Sucrose, glucose and fructose were analysed in 35 samples from lead clarified filtrates and filtration filtrates. According to the specific rotation of these sugars, derived pol was calculated (Schoonees, 2003) from the lead clarification pol and filtration pol results (Table 4). In these 35 samples, the pol\%cane differences were 0.09 and the pol\%cane derived differences were 0.07.

Fructose and glucose concentrations are lower in lead filtrates (0.50%) than in filtration filtrates (0.66%). This 0.16% decrease in reducing sugars content decreases the pol measurement by 0.05. The 0.08 differences observed between pol measurements are mainly explained by the removal of reducing sugars by lead.

Table 4—Pol in cane derived and sugar content of filtrates.

<table>
<thead>
<tr>
<th>Glucose</th>
<th>Fructose</th>
<th>Sucrose</th>
<th>Pol%cane</th>
<th>Pol%cane derived</th>
</tr>
</thead>
<tbody>
<tr>
<td>g/100 g Juice</td>
<td>g/100 g Cane</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pol882 (filtration)</td>
<td>0.33 ±0.24</td>
<td>0.30 ±0.22</td>
<td>18.25</td>
<td>14.44</td>
</tr>
<tr>
<td>Pol589 (lead clarification)</td>
<td>0.28 ±0.23</td>
<td>0.22 ±0.18</td>
<td>18.28</td>
<td>14.53</td>
</tr>
<tr>
<td>Differences</td>
<td>0.05 ±0.06</td>
<td>0.07 ±0.08</td>
<td>-0.03</td>
<td>-0.09</td>
</tr>
</tbody>
</table>

A possible limitation to the explanation of the differences observed is that the sample selections were not randomised. They were sampled using the maximum and minimum differences observed between lead and non-lead methods. This sampling methodology implies high standard
deviation for the different analyses. The results can be used to explain average differences but should be evaluated with care.

**Filtration pol for factory control**

Comparisons of pol_{589} and pol_{882} were carried out on mixed juice, bagasse, mud and molasses.

**Pol by filtration is different from pol by lead clarification**

Differences between pol by lead clarification and by filtration vary depending on the factory product in question (Table 5). For mixed juice, pol by filtration is lower than pol by lead clarification, meaning that pol by filtration underestimates sucrose by 0.13% cane on average. For bagasse, both pol values are close to the sucrose values. For mud, pol by filtration is closer to sucrose values than lead clarification. For molasses, pol by filtration is lower than pol by lead clarification, resulting in an important underestimation of sucrose.

<table>
<thead>
<tr>
<th>Differences compared to pol_{589}</th>
<th>Pol_{882}</th>
<th>Sucrose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixed juice</td>
<td>-0.07</td>
<td>+0.13</td>
</tr>
<tr>
<td>Bagasse</td>
<td>+0.01</td>
<td>-0.03</td>
</tr>
<tr>
<td>Mud</td>
<td>+0.06</td>
<td>+0.09</td>
</tr>
<tr>
<td>Molasses</td>
<td>-3.82</td>
<td>+2.60</td>
</tr>
</tbody>
</table>

**Filtration pol for sugar loss measurements**

The results show that filtration pol is suitable for measuring sugar losses but modifies the standard values. The entire sugar mill uses laboratory measurements to make a mass balance for measuring sugar losses. Results based on lead clarification and filtration pol show that sugar losses will be affected (Table 6). As the changes will be the same each week, a relative comparison can be made on a weekly basis.

Mixed juice sugar content will appear to be lower with filtration pol. For sugar mills that use mass balance (Cane + Imbibition = Mixed juice + Bagasse) to calculate pol%cane, the measurement for sugar entering the factory will decrease, resulting in an apparent decrease in undetermined losses. For Reunion Island sugar mills, this implies a decrease of 0.08 in pol%cane.

Sugar losses in bagasse and in mud will not be affected by the change in method. Sugar losses in molasses will decrease by 0.25, resulting in an increase of 0.25 in undetermined losses with the change in method. In Reunion, molasses losses are calculated on a weekly composite sample analysed by HPAEC-PAD, meaning that the pol method will not affect sugar losses in molasses. These differences have been examined in more detail by Corcodel and Hoareau (2009).

**Table 6—Sugar losses calculated with lead clarification pol, filtration pol and sucrose.**

<table>
<thead>
<tr>
<th></th>
<th>Lead clarification pol</th>
<th>Filtration pol</th>
<th>Filtration pol</th>
<th>Sucrose</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pol_{589}</td>
<td>pol_{882}</td>
<td>pol_{882}</td>
<td></td>
</tr>
<tr>
<td>Pol%cane calculated from mass</td>
<td>12.50</td>
<td>12.42</td>
<td>12.42</td>
<td>12.63</td>
</tr>
<tr>
<td>balance in the milling</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>tandem*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sugar losses in bagasse</td>
<td>0.30</td>
<td>0.30</td>
<td>0.30</td>
<td>0.29</td>
</tr>
<tr>
<td>Sugar losses in mud</td>
<td>0.11</td>
<td>0.11</td>
<td>0.11</td>
<td>0.11</td>
</tr>
<tr>
<td>Sugar losses in molasses</td>
<td>1.29</td>
<td>1.29</td>
<td>1.04</td>
<td>1.29</td>
</tr>
<tr>
<td>Total sugar losses</td>
<td>1.99</td>
<td>1.92</td>
<td>1.92</td>
<td>2.12</td>
</tr>
<tr>
<td>Undetermined losses</td>
<td>0.29</td>
<td>0.21</td>
<td>0.46</td>
<td>0.43</td>
</tr>
</tbody>
</table>

* Cane + Imbibitions = Mixed Juice + Bagasse
A possible limitation of this paper is the lack of clear explanation for the differences between lead clarification and filtration pol for factory products. Nevertheless, the polarisation of sugarcane compounds could be more fully investigated.

Pol by filtration has been used for factory control in Reunion Island since 2005. Mill staff are using laboratory results as previously. The main problematic point is the new system of reference used for results concerning molasses.

**Conclusions**

Polarisation by filtration is suitable for cane payment and factory control. Results for pol in cane by filtration are on average 0.08% lower than for lead clarification pol. Factory control figures are modified, with a decrease of apparent sucrose entering the mills, resulting in a decrease of undetermined losses.

Pol analysis without lead is an environmentally friendly, non hazardous method. As polarimetry is used to estimate sucrose levels, non-lead pol is sufficient for payment and factory balance purposes. As the lead standard is disappearing, this new standard can be adopted by sugar technologists.

In Reunion Island, sugar mills started to use filtration pol analysis methods in 2005 for factory control and in 2009 for cane payment.

**Acknowledgment**

We would like to thank all the staff at eRcane for their help in preparing these data, with special thanks to Mélanie David who carried out most of the pol comparisons at CTICS during the 2007 and 2008 seasons.

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LA POLARISATION PAR FILTRATION PERMET LE PAIEMENT DE LA CANNE ET LE CONTROLE DE FABRICATION

Par

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Résumé

Les analyses sucrières sont utilisées mondialement pour mesurer la qualité de la canne ainsi que des produits de la sucrerie. La polarimétrie est l’analyse fondamentale du saccharose pour mesurer la qualité de la canne et les performances industrielles. La méthode de pol nécessite une étape de clarification généralement réalisée avec de l’acétate de plomb. Une méthode sans plomb a été développée par filtration. Cette méthode par filtration permet l’analyse de la canne pour le paiement et les produits de fabrication pour les bilans de fabrication (jus mélangés, bagasse, écume et mélasse). Les résultats sur la détermination de la richesse indiquent que l’analyse par filtration est inférieure de 0.08 comparé à l’analyse par clarification au plomb. Le résultat sur les bilans de fabrication vont être une baisse (–0.08) de la mesure du sucre en entrée usine qui va conduire à une baisse (–0.08) des pertes indéterminées. Pour conclure, la méthode de polarisation par filtration permet le paiement de la canne et le contrôle de fabrication. Cette méthode est utilisée à La Réunion pour le paiement de la canne et le contrôle de fabrication.
POLARIZACIÓN POR FILTRACIÓN PARA PAGO
DE CAÑA Y CONTROL DE FÁBRICA

Por

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PALABRAS CLAVE: Calidad de Caña,
Análisis, Pol, Plomo, Filtración.

Resumen

Los análisis de laboratorio se utilizan a nivel mundial para determinar la calidad de la caña y los productos de su procesamiento. La polarimetría es el análisis básico de sacarosa en el laboratorio para determinar calidad de caña y desempeño fabril. Las mediciones de pol requieren un paso de clarificación que es usualmente efectuado con subacetato de plomo. Se ha desarrollado un método basado en filtración y que no hace uso del subacetato. Este método ha sido caracterizado para determinar su adaptabilidad en análisis de caña con fines de pago y para productos de la fábrica (jugo diluido, bagazo, cachaza y mieles) para control de proceso. Los resultados de pol en caña son en promedio un 0.08% más bajos con el método de filtración que con el método estándar de clarificación. Los resultados para control de fábrica muestran que la sacarosa aparente entrando al molino disminuye en 0.08 lo que resulta en un decrecimiento de las pérdidas indeterminadas. Para concluir, la polarización por filtración es adecuada para pago de caña y control fabril y es usada actualmente en la Isla Reunión para esos propósitos.
CHARACTERISATION OF CUBAN FINAL MOLASSES FROM 1999 TO 2008

By
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KEYWORDS: Molasses, Oligosaccharides, True Purity.

Abstract
SUCROSE loss in molasses is a common concern of the sugar industry worldwide as the largest contributor to total losses. In Cuba the loss is just less than 60%. Various factors influence sucrose solubility increase, among which is the nature of impurities present in the molasses. Molasses from different Cuban mills were characterised during the seasons 1999 to 2008, to determine the constituents of greatest influence in increasing the purity. Samples were analysed for soluble solids (brix), conductivity ash, sludge, sucrose crystals, sucrose, glucose, fructose and oligosaccharides. Impurities, water ratio (I/W) and apparent and true purities of samples studied were determined. The average value of true purity in samples was 43.37%. The biggest difference between samples was the impurities content; for example, the percentage of oligosaccharides ranged over an order of magnitude. The correlation between impurities, water ratio and true purity was confirmed, and it was also found that oligosaccharides percent correlated significantly (p < 0.001) with the above characters. A total of eighteen oligosaccharides was detected in the molasses studied. The presence of each of these species, both qualitatively and quantitatively, differed from sample to sample. Only one of these oligosaccharides showed significant correlation (p<0.005) with molasses sucrose content (pol). The present work highlights oligosaccharide influence on molasses final purity, so these compounds should be taken into account in formulating the Cuban equation for the target purity.

Introduction
In Cuba since the early eighties, the purity of molasses increased well above historical levels. Loss of sucrose in molasses is produced by a number of factors so numerous and in a variety of complex interactions that cannot be studied in a simple manner. Some of these cases probably arise long before the manufacturing process of sugar cane, in its cultivation and harvest (Eggleston et al., 2001). Final molasses provides the largest contribution to the loss of sucrose in the sugar making process. Exhaustion of molasses depends mainly on sucrose solubility, which is influenced by temperature and the composition and concentration of different compounds. It has been established that reducing sugars decrease sucrose solubility and most inorganic salts increase the solubility (Lajos, 2000). It is well known that it is not feasible to remove all the sugar in cane juice entering the factory; however, it is possible to improve sucrose recovery to decrease losses that occur during the manufacturing process; in fact, good sucrose recovery depends on the crystallisation process, which in turn depends on exhaustion of massecuites and molasses.

This has been studied by many researchers in the world looking for impurities that have a higher incidence in sucrose crystallisation, both in the form of crystal (Hormaza, 2003), and crystallisation mechanism (Vaccari, 1998). To find an equation to model the behaviour of molasses purity, it is necessary to calculate values of molasses true purity and other parameters that could influence it, like reducing sugar, ash, etc, and then use data accumulated over time to look for variables with strong correlation with purity to determine the constants of the equation that defines it.
This paper presents a compilation of information in the Cuban Sugar Research Institute on the characterisation of Cuban final molasses of sugarcane over the last decade. In addition, results are shown of statistical data analysis targeting which molasses components influence purity and thereby increase losses of sucrose in the manufacturing process.

Materials and methods

Samples

Final molasses samples produced by different Cuban sugar factories, spread over the country were studied. Samples were constituted by ten-day final molasses samples accumulated at each factory during three harvest periods during the seasons 1999, 2000, 2001, 2002, 2005, 2007 and 2008.

Physical – chemical analysis

Molasses samples were analysed according to ICUMSA methods or Cuban National Bureau standards (2009) according to the following list:

- Brix: refractometric dry substance. ICUMSA method GS4-13
- Sludge (insoluble material): NC 710:2009. It is based on precipitation of insoluble materials contained in final molasses and centrifugation at 3500 rpm for 10 minutes.
- Sucrose crystals: Total insoluble solids are made up of sludge and sucrose crystals that are suspended, so washing the pellet formed after centrifugation with distilled water will enable these two components to be separated and, and by weight difference, the content of crystals can be determined.

High Performance Liquid Chromatography (HPLC) analyses

Determinations for fructose, glucose, sucrose and oligosaccharides were performed in a Knauer HPLC equipment with cation-exchange column EuroKat Ca 300 × 7.8 mm to 85 °C with a water flow of 0.6 mL/min and refractive index detector. A typical chromatogram is shown in Figure 1.

Fig.1—Molasses HPLC cation-exchange characteristic profile. Peaks 1–3 oligosaccharide, 4 sucrose, 5 glucose, 6 fructose.
Determination of oligosaccharide composition on molasses

Determinations of different oligosaccharides present in molasses were made by using an anion-exchange high resolution chromatographic system (HPAEC, Figure 2) with amperometric pulse detector (PAD) Dionex instrument, using a CarboPac 1 column, 300 mm × 7.8 mm with a gradient of 0.05 N sodium hydroxide in 0.1 N sodium acetate to 0.1 N sodium hydroxide in 0.1 N sodium acetate. A hydrolysed dextran was used as a standard to determine the oligosaccharide species polymerisation degree.

Fig. 2—Molasses HPAEC characteristic profile. Differential fractions considered as oligosaccharides have been underlined.

Statistical analysis

Data obtained from chemical–physical analysis as well as chromatographic analyses were processed using the statistical program Statgraf version 5.1.

Results

Characterisation of Cuban final molasses in the period 1999–2008

An average 39 samples of final molasses were analysed per season. All results are expressed as averages of molasses samples analysed in each of the seasons studied. Table 1 shows the results of brix, ash, apparent and true sucrose, glucose, fructose, oligosaccharide, crystals, sludge and impurity/water ratio in molasses analysed.

Brix has ranged between 91% and 82%, showing a clear tendency to decline over the last decade, probably due to extra water addition to molasses after the centrifugal to reduce viscosity.

Sucrose crystal content ranged between 4.3 and 11.5%. A possible explanation for the increase in sugar crystal per centage was the increment of crystal fragility due to crystal habit deformations by a high concentration of oligosaccharide in final molasses (Hormaza, 2003). In 2001, the highest contents of crystals in Cuban molasses were reported which coincided with the highest content of oligosaccharides detected that year. Sludge content in the molasses remained below 2%. Impurity/water ratios ranged from 2.8 to 6.9% respectively while ash content ranged from 9.8 to 15.5%.

Apparent sucrose in Cuban molasses showed an increase of five percentage points over the last decade. Furthermore, sucrose content in final molasses in the period 1999–2008 has averaged between 30% in 2000 to 46% in 2007. Reducing sugars on the other hand maintained little variability over time. As for the rest of the non-sucrose carbohydrates, oligosaccharide net content fluctuated more between harvests.
Table 1—Cuban molasses composition during 1999–2008. Results expressed as % by mass.

<table>
<thead>
<tr>
<th>Year</th>
<th>Brix</th>
<th>Ash</th>
<th>App. sucrose</th>
<th>True sucrose</th>
<th>Glucose</th>
<th>Fructose</th>
<th>Oligos</th>
<th>Crystals</th>
<th>Sludge</th>
<th>I/W</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>Avg</td>
<td>90.62</td>
<td>11.20</td>
<td>34.10</td>
<td>35.25</td>
<td>6.09</td>
<td>6.98</td>
<td>6.13</td>
<td>3.99</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>86.05</td>
<td>8.60</td>
<td>23.50</td>
<td>27.07</td>
<td>3.14</td>
<td>3.27</td>
<td>2.82</td>
<td>0.15</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>95.36</td>
<td>16.80</td>
<td>40.70</td>
<td>42.67</td>
<td>9.03</td>
<td>10.5</td>
<td>10.13</td>
<td>12.06</td>
<td>2.05</td>
</tr>
<tr>
<td>2000</td>
<td>Avg</td>
<td>90.79</td>
<td>12.13</td>
<td>31.98</td>
<td>29.81</td>
<td>6.23</td>
<td>7.59</td>
<td>7.4</td>
<td>2.88</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>88.75</td>
<td>9.56</td>
<td>25.91</td>
<td>26.51</td>
<td>3.16</td>
<td>5.23</td>
<td>4.85</td>
<td>1.12</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>95.46</td>
<td>31.34</td>
<td>44.12</td>
<td>36.84</td>
<td>9.67</td>
<td>12.03</td>
<td>9.72</td>
<td>12.17</td>
<td>2.50</td>
</tr>
<tr>
<td>2001</td>
<td>Avg</td>
<td>89.20</td>
<td>11.77</td>
<td>34.7</td>
<td>36.5</td>
<td>5.88</td>
<td>7.33</td>
<td>19.58</td>
<td>11.2</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>85.20</td>
<td>9.66</td>
<td>28.78</td>
<td>30.17</td>
<td>3.70</td>
<td>4.77</td>
<td>15.41</td>
<td>4.72</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>92.00</td>
<td>14.70</td>
<td>41.08</td>
<td>43.11</td>
<td>13.72</td>
<td>17.50</td>
<td>30.10</td>
<td>18.23</td>
<td>1.63</td>
</tr>
<tr>
<td>2002</td>
<td>Avg</td>
<td>88.16</td>
<td>14.77</td>
<td>34.68</td>
<td>35.66</td>
<td>7.17</td>
<td>9.46</td>
<td>13.94</td>
<td>5.39</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>82.76</td>
<td>11.05</td>
<td>29.57</td>
<td>24.21</td>
<td>4.47</td>
<td>6.05</td>
<td>5.33</td>
<td>2.60</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>96.76</td>
<td>22.15</td>
<td>42.44</td>
<td>46.12</td>
<td>13.07</td>
<td>16.13</td>
<td>44.20</td>
<td>19.21</td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td>Avg</td>
<td>86.24</td>
<td>9.2</td>
<td>37.5</td>
<td>34.5</td>
<td>5.76</td>
<td>6.97</td>
<td>14.18</td>
<td>4.70</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>68.8</td>
<td>0.28</td>
<td>32.52</td>
<td>28.17</td>
<td>3.83</td>
<td>4.73</td>
<td>12.41</td>
<td>0.34</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>101.44</td>
<td>17.9</td>
<td>44.4</td>
<td>41.11</td>
<td>13.90</td>
<td>16.40</td>
<td>27.10</td>
<td>19.01</td>
<td>3.79</td>
</tr>
<tr>
<td>2007</td>
<td>Avg</td>
<td>87.00</td>
<td>11.2</td>
<td>36.36</td>
<td>49.09</td>
<td>9.21</td>
<td>5.58</td>
<td>13.15</td>
<td>3.67</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>77.74</td>
<td>9.00</td>
<td>31.08</td>
<td>38.15</td>
<td>5.51</td>
<td>2.47</td>
<td>4.91</td>
<td>1.89</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>94.20</td>
<td>13.27</td>
<td>50.22</td>
<td>70.62</td>
<td>11.28</td>
<td>10.11</td>
<td>15.62</td>
<td>5.89</td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>Avg</td>
<td>83.86</td>
<td>4.80</td>
<td>39.40</td>
<td>34.11</td>
<td>4.39</td>
<td>5.05</td>
<td>15.98</td>
<td>4.28</td>
<td>0.83</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>66.48</td>
<td>2.40</td>
<td>31.40</td>
<td>16.02</td>
<td>3.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.10</td>
<td>1.04</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>89.40</td>
<td>7.90</td>
<td>46.90</td>
<td>56.86</td>
<td>12.61</td>
<td>9.05</td>
<td>33.91</td>
<td>9.19</td>
<td>1.67</td>
</tr>
</tbody>
</table>

The purity of final molasses in the last decade has shown an upward trend, reaching the lowest values (34 true and 36 apparent) in the harvest of 2002. The maximum value of true purity was 50% in 2007 whereas the highest apparent purity was 46% in the harvest of 2008.

![Fig. 3—Trend of true and apparent purities of final molasses in the period 1999–2008.](image-url)
Determination of oligosaccharide species in Cuban molasses

Using high resolution anion-exchange chromatographic techniques with pulse amperometric detector, a total of 18 different oligosaccharides with degree of polymerisation between three and seven units were determined.

Some of those oligosaccharides were identified as gentibiose, leucrose, raffinose, melicitose, neo-kestose, 6-kestose and maltotriose. A total of eleven unidentified species were detected, five of these comprised three monosaccharide units and the remainder with a degree of polymerisation between four and seven. The oligosaccharide composition and frequency of the molasses studied were very heterogeneous, finding between two and ten of these species in them (Table 2).

Table 2—Oligosaccharides detected in cane molasses. Minimum and maximum expressed as relative percent of total oligosaccharides.

<table>
<thead>
<tr>
<th>Oligosaccharide</th>
<th>Relative percent</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>minimum</td>
<td>maximum</td>
</tr>
<tr>
<td>gentibiose</td>
<td>1.05</td>
<td>55.13</td>
</tr>
<tr>
<td>melicitose</td>
<td>0.98</td>
<td>12.76</td>
</tr>
<tr>
<td>leucrose</td>
<td>1.40</td>
<td>1.45</td>
</tr>
<tr>
<td>neo-kestose</td>
<td>0.98</td>
<td>1.00</td>
</tr>
<tr>
<td>1-kestose</td>
<td>0.27</td>
<td>70.80</td>
</tr>
<tr>
<td>6-kestose</td>
<td>58.70</td>
<td>58.90</td>
</tr>
<tr>
<td>maltotriose</td>
<td>1.20</td>
<td>3.60</td>
</tr>
<tr>
<td>unknown 1</td>
<td>19.10</td>
<td>19.40</td>
</tr>
<tr>
<td>unknown 2</td>
<td>14.68</td>
<td>63.15</td>
</tr>
<tr>
<td>unknown 3</td>
<td>9.68</td>
<td>9.70</td>
</tr>
<tr>
<td>unknown 4</td>
<td>11.37</td>
<td>79.80</td>
</tr>
<tr>
<td>unknown 5</td>
<td>1.40</td>
<td>15.00</td>
</tr>
<tr>
<td>unknown 6</td>
<td>20.53</td>
<td>20.60</td>
</tr>
<tr>
<td>unknown 7</td>
<td>2.00</td>
<td>85.00</td>
</tr>
<tr>
<td>unknown 8</td>
<td>7.16</td>
<td>17.25</td>
</tr>
<tr>
<td>unknown 9</td>
<td>4.75</td>
<td>21.25</td>
</tr>
<tr>
<td>unknown 10</td>
<td>2.70</td>
<td>4.20</td>
</tr>
<tr>
<td>unknown 11</td>
<td>0.30</td>
<td>3.00</td>
</tr>
</tbody>
</table>

Statistical analysis

All data obtained from the characterisation of final molasses during the past decade were used for statistical analysis looking for correlations between these variables and the true and apparent purities so that, once localised, it would be useful as a tool for a better understanding of the manufacturing process, providing guidance on what aspects to consider for further development of an equation to predict target purity.

Table 3 shows the Pearson product moment correlations between pairs of variables. These correlation coefficients range from −1 to +1 and measure the strength of the linear relationship between variables.

It also shows the number of pairs of data used to calculate each coefficient. The third row is a P-value which confirms the importance of the statistic of the estimated correlations.

P-values below 0.05 indicate statistical significance of non-zero correlation for a confidence level of 95%.
Table 3—Correlation analysis between apparent and true purities and some variables.

<table>
<thead>
<tr>
<th></th>
<th>Fructose</th>
<th>Glucose</th>
<th>Reducing sugars</th>
<th>Ash</th>
<th>Oligosaccharides</th>
<th>I/W</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Apparent purity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coefficient</td>
<td>−0.3356</td>
<td>−0.2492</td>
<td>−0.3080</td>
<td>0.0896</td>
<td>0.1946</td>
<td>−0.2168</td>
</tr>
<tr>
<td>Data</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>p-value</td>
<td>0.0006*</td>
<td>0.0124*</td>
<td>0.0018*</td>
<td>0.3755</td>
<td>0.0523</td>
<td>0.0303*</td>
</tr>
<tr>
<td><strong>True purity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coefficient</td>
<td>−0.044</td>
<td>−0.0262</td>
<td>−0.0373</td>
<td>0.0338</td>
<td>0.4018</td>
<td>−0.2453</td>
</tr>
<tr>
<td>Data</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>p-value</td>
<td>0.6641</td>
<td>0.7961</td>
<td>0.7129</td>
<td>0.7388</td>
<td>0.0000*</td>
<td>0.0139*</td>
</tr>
</tbody>
</table>

Influence of variables in real and apparent purities

Multiple regression analysis was performed with true purity as the dependent variable and as independent variables those in which there was a linear non-zero correlation with the first. It was determined that the percent of oligosaccharides and the impurity/water ratios present a statistically significant relationship with true purity at the 99% confidence level with these independent variables responsible for 17.7% of the true purity variability. However, no correlation was found between ash content and reducing sugars with true purity (Table 4).

Table 4—Multiple regression analysis results with true purity as the dependent variable.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimation</th>
<th>Standard error</th>
<th>T statistic</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>42.98490</td>
<td>1.80582</td>
<td>23.80350</td>
<td>0.00001</td>
</tr>
<tr>
<td>I/W</td>
<td>−1.02952</td>
<td>0.23148</td>
<td>−4.44743</td>
<td>0.00002</td>
</tr>
<tr>
<td>Oligosaccharide</td>
<td>0.17830</td>
<td>0.06576</td>
<td>2.71115</td>
<td>0.00740</td>
</tr>
</tbody>
</table>

R²=0.176781

Using the same method, the existence of a statistically significant relationship (p <0.01) exists between the apparent purity and the two independent variables of glucose and reducing sugars that accounts for 26.5% of the variability of the apparent purity (Table 5).

Table 5—Multiple regression analysis results with apparent purity as the dependent variable.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimation</th>
<th>Standard error</th>
<th>T statistic</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>45.82190</td>
<td>1.74982</td>
<td>26.18660</td>
<td>0.00003</td>
</tr>
<tr>
<td>Reducing sugars</td>
<td>−1.53387</td>
<td>0.31665</td>
<td>−4.84405</td>
<td>0.00002</td>
</tr>
<tr>
<td>Glucose</td>
<td>1.86792</td>
<td>0.62203</td>
<td>3.00290</td>
<td>0.00330</td>
</tr>
</tbody>
</table>

R²=0.265387

Influence of oligosaccharides on pol

To determine which oligosaccharides have more influence on the pol in the mashes, all oligosaccharides detected were analysed for Pearson’s product moment correlations and non-zero correlations were obtained between pairs of variables for a confidence level of 95%. A linear regression analysis was undertaken using pol as the dependent variable to determine those independent variables with a linear non-zero correlation with pol.
It was determined that from the oligosaccharides present only one of them (Unknown 8), with polymerisation degree between four and seven, had a non-zero correlation with the pol (p <0.01) so this oligosaccharide, identified with retention time of 26.88 minutes, is responsible for 30 percent of the variability of pol data (Table 6).

<table>
<thead>
<tr>
<th>Dependent variable: Pol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
</tr>
<tr>
<td>constant</td>
</tr>
<tr>
<td>Unknown 8</td>
</tr>
</tbody>
</table>

Discussion

Results of analyses of Cuban molasses during the last decade have shown that oligosaccharides showed greater variability, reaching a maximum value in 2001 season and resulted in an increment of sucrose crystal content in molasses that year high above average values.

In general, there was a tendency for the oligosaccharide content to increase probably as a result of delays between cut and crush (Ramos, 2002). A similar trend was observed for true sucrose content (Figure 3) due to problems caused by these compounds in the crystallisation process.

Ash and reducing sugars showed little variability in the samples which could explain why no correlation was observed between these variables and purity of final molasses unlike those reported for other regions (Gil et al., 2001; Miller et al., 1998; Smith, 1995). It appeared there was a correlation, with 95% confidence, between the total oligosaccharide content and I/W with true purity (Table 4). Similar results have been reported previously by Rein (2002).

The qualitative and quantitative composition of oligosaccharides in sugarcane juice and in final molasses depends on a lot of causes, both agricultural and industrial. It is characteristic of the variety and age of the plant and tends to increase after harvesting, often by the action of microorganisms (SMRI, 1992). The oligosaccharide composition results found heterogeneous mixtures of between two and ten different oligosaccharides in the molasses samples studied.

In early works on molasses oligosaccharides, Binkley (1964) identified 1 kestose, 6-kestose, raffinose, nistose, planteose and fructosil 1 kestose. Later Morel du Boil (1995) reported different mixtures of sugarcane oligosaccharides, neo kestose, 6-kestose and 1-kestose according to different months of harvesting. The present study detected a total of 18 different oligosaccharides (Table 2), including neo kestose, 6 kestose and 1-kestose as has been reported, but the oligosaccharide species most frequently detected was another unidentified with a similar degree of polymerisation.

The present study showed that one of these species, Unknown 8, correlated with the reading of pol contributing 30% of the variability of the pol. This oligosaccharide, together with the glucose and reducing sugars in the molasses, introduces another source of variability to be considered in determining the apparent purity of Cuban molasses.

Conclusions

Cuban molasses produced in different sugar factories, spread throughout the country, for seven seasons within the period from 1999 to 2008 has been characterised. The analyses have found variables that influence the pol and purity of Cuban molasses. It was demonstrated that, from all of the oligosaccharides detected only one, Unknown 8, was a source of variability in the pol reading. It was also shown that the level of glucose and reducing sugars influenced the apparent purity of molasses and the total content of oligosaccharides and the I/W affects the true purity of these molasses.
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CARACTÉRISATION DE LA MÉLASSE FINAL CUBAINE DE 1999 À 2008

Par

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MOTS-CLEFS: Mélasse, Oligosaccharides, Pureté.

Résumé
La perte de saccharose dans la mélasse est une préoccupation commune de l’industrie du sucre dans le monde entier comme le plus important contributeur des pertes totales. À Cuba, la perte est au dessous de 60%. L’augmentation de la solubilité du saccharose est influencée par divers facteurs, parmi lesquels est la nature des impuretés présentes dans la mélasse. Les mélasses des différentes usines cubaines ont été caractérisées durant les saisons 1999–2008, afin de déterminer les composantes avec la plus grande influence pour augmenter la pureté. Les échantillons ont été analysés pour les solides solubles (brix), la cendre (conductivité), boues, cristaux de saccharose, saccharose, glucose, fructose et oligosaccharides. Le rapport impuretés / eau (I/W) et les puretés apparaentes et réelles des échantillons étudiés ont été déterminés. La valeur moyenne des puretés réelles dans les échantillons était 43.37%. La plus grande différence entre les échantillons était la teneur en impuretés ; par exemple, le pourcentage d’oligosaccharides variait par un ordre de grandeur. La corrélation entre I/W et la pureté réelle a été confirmée, et on a également constaté que la concentration des oligosaccharides corrélées significativement (p 0.001) avec les caractères ci-dessus. Un total de dix-huit oligosaccharides a été détecté dans la mélasse étudiée. La présence de chacune de ces espèces, tant qualitativement et quantitativement, diffère d’un échantillon à l’autre. Un seul de ces oligosaccharides a montré une corrélation significative (p 0.005) avec le contenu de saccharose de mélasse (pol). Ce travail rehausse l’influence des oligosaccharides sur la pureté de la mélasse finale ; ces composés devraient donc être pris en compte dans la formulation de l’équation cubaine de la pureté cible.
CARACTERIZACIÓN DE LAS MIELES FINALES EN CUBA DESDE 1999 HASTA 2008

Por

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PALABRAS CLAVE: Mieles, Oligosacáridos, Pureza Real.

Resumen
LAS PÉRDIDAS de sacarosa en miel final son una preocupación de la industria azucarera a nivel mundial por ser las que más contribuyen a las pérdidas totales. En Cuba la pérdida es un poco menos del 60%. Varios factores influencian el incremento de solubilidad de la sacarosa, entre los cuales está la naturaleza de las impurezas presentes en las mieles. Se caracterizaron las mieles de diferentes ingenios cubanos durante las zafra de 1999 a 2008, para determinar los constituyentes de mayor influencia en el incremento de pureza. Las muestras se analizaron para sólidos solubles (brix), cenizas por conductividad, lodos, cristales de sacarosa, sacarosa, glucosa, fructosa, y oligosacáridos. Las impurezas, la razón con el agua (I/W) y las purezas real y aparente se determinaron para las muestras estudiadas. El valor promedio de la pureza real fue de 43.37%. La mayor diferencia entre muestras estuvo en el contenido de cenizas; por ejemplo el porcentaje de oligosacáridos varió por encima de un orden de magnitud. La correlación entre impurezas, la razón de agua, y pureza real fue confirmada, y se encontró que el porcentaje de oligosacáridos correlacionó significativamente (p<0.001) con los factores anteriores. Se identificaron 18 oligosacáridos en las mieles estudiadas. La presencia, tanto cuantitativamente como cualitativamente, varió entre muestras. Solamente uno de los 18 mostró correlación significativa (p<0.005) con el contenido de sacarosa en las mieles (Pol). El presente trabajo señala la influencia de los oligosacáridos en la pureza de las mieles, por lo que estos compuestos deben ser tenidos en cuenta en la formulación de la ecuación cubana para la pureza objetivo.
AN ANALYTICAL OVERVIEW OF THE HISTORICAL EVOLUTION OF SOME PERFORMANCE INDEXES OF THE COLOMBIAN SUGAR MILLS

By

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KEYWORDS: Analysis, Performance, Review, Standardisation.

Abstract

In 1993, the Colombian sugar industry recognised the importance of creating a reliable Standard Measuring System (SMS) for the sugar factories, with the purpose of developing tools for management processes. This system included sampling, analytical procedures and calculation modules. It was generated in conjunction with experts from Sugar Research Institute in Australia (Ken Miller and Geoffrey Bentley), the chief chemist of each sugar factory and the technical staff from Cenicaña. Since January 1998, the Factory Process Research Program at Cenicaña, together with the staff of the 10 main Colombian sugarcane mills, began the construction of an integrated database, focusing on the registry of 42 process variables measured and/or calculated in each factory. Each variable reported by the sugar mills was based on monthly weighted averages. The predetermined set of variables comprised those related to cane quality, sucrose balance (related to undetermined loss), energy usage and time use efficiency. Because the SMS has a very strong dynamic behaviour, a parallel program for assessing the quality of the reported information was established (Calero, et al., 2006). Over this 10 year period, the improvement in sucrose % cane and factory efficiencies is notable. From 2002 until now, the increment in 0.25 units in sucrose % cane and 1 percent unit in overall recovery (OR) represent an additional production of 69 860 tonnes of sugar for a cane crush of 20 million tonnes per year.

Introduction

The Colombian Sugarcane Research Center (Cenicaña) is a private, non-profit corporation, founded in 1977 by the Association of Sugarcane Growers of Colombia (Asocaña) representing the sugar agro-industry located in the Cauca River Valley. Cenicaña carries out research programs on varieties, agronomical practices and factory processes, and has support services in economic and statistical analyses, information and documentation, computer technology, technical cooperation and technology transfer. It provides laboratory analytical services, administers the Automated Weather Network (AWN) stations, and continually updates the digital cartography of the cultivated area.

The sugar industry in Colombia has three cane growers’ associations, one research centre, one cane technicians’ association, two trade firms, 13 sugar mills and a large number of cane grower enterprises. Five sugar mills established distilleries to produce ethanol at the end of 2005 in response to Law 693 of 2001, which mandated oxygenating vehicular gasoline with 10% (by volume) of fuel ethanol.

Factory performance indices

The standardised monthly inter mill benchmarking started in January 1998. Thirteen sugarcane mills report 42 indices relating to sugarcane quality, time efficiency, sucrose extraction,
boiling house recovery (BHR), overall recovery, and energy usage. This paper shows the trends of the monthly average values of ten mills, during the first ten years of the SMS.

**Crushed cane and sugar production**

In 1999, the variety CENICAÑA Colombia (CC) 85-92 became the first commercial variety in the area planted by the Colombian sugar industry in the Cauca River Valley. Crushed cane has grown from approximately 17 million tonnes of cane annually in 1998 to a maximum value just under 21 million tonnes in 2004. The monthly average of cane crushed was 1 600 000 tonnes, with a minimum of 609 228 tonnes in October 2008 as a result of the blockade of eight sugar mills by cane cutters. Monthly values around 2 million tonnes are frequently obtained in August and September during the dry season (Figure 1).

A greater stability is observed during the years 2002 and 2006 when around 20 million tonnes per year were crushed. This fact is explained by the dry periods experienced during these years with an annual average rainfall of 1000 mm. This was the lowest value registered in the 34 AWN stations placed throughout the Cauca River Valley (Informe anual, Cenicaña, 2008).

![Figure 1—Monthly averages for cane and sugar production in Colombia.](image)

The increased availability of the cane variety CC85-92 from 2002 led to a productivity increase on average of 10% more cane per hectare (tch). Moreover, there was an increase in milling throughput of 7% per day and a 2% increase in the overall time efficiency.

The sugar production per year ranged between 2 million tonnes and 2.4 million tonnes. The Colombian sugar industry produces refined sugar in seven refineries and, raw sugar, white sugar, special direct white sugar (colour below 150 IU) and organic sugar. The amount of sugar depends on the crush rate, cane quality and the factory efficiencies.

The monthly average crush rate was 186 911 tonnes cane per hour, and this ranged between 70 853 and 249 981 tonnes cane per hour. As in the case of total cane crushed, the minimum value was obtained in October 2008, because of the blockade (Figure 1). The yield expressed as kg of sugar of 99.7 pol per 100 kg of cane has varied from 11.30 to 11.93 with a yearly average value of 11.70.

**Cane quality**

The trend to higher content of sucrose % cane (Figure 2) and lower industrial fibre % cane (Figure 3) coincided with the fact that from 2001 the cane variety CC 82-92 became the most
harvested in the industry. In 2008, this variety was harvested in 70% of the cane area. Between 1998 and 2001, the average sucrose % cane and fibre % cane were 13.18% and 15.10% respectively and between 2002 and 2008 the averages were 13.43% and 14.77%. The maximum content of sucrose in cane, 14.62%, was reached in September 2006. During 1996–2002, the Factory Process Research Program at Cenicaña developed a project called ‘Reduction of Sucrose losses between field and factory’. One of the main objectives of this project was to determine the rate of sucrose deterioration due to storage time which ranged from 0.0015–0.02 sucrose % per hour (Briceño, 2006). The mills reduced the storage time from an average of 50 h–60 h down to 30–42 h (Larrahondo and Briceño, 2001).

![Fig. 2—Monthly averages for sucrose % cane in Colombia.](image1)

The industrial fibre includes the cane fibre and the insoluble mud solids measured in mixed juice. The higher values of fibre reported in April, May and December are associated with the rainy periods experienced during these months (Figure 3).

![Fig. 3—monthly averages for industrial fibre % cane in Colombia.](image2)
Reduced extraction at 12.5% fibre.

All the sugar factories have milling tandems and, of the ten mills, three have knives only, three mills have knives and medium duty shredders, two have knives and heavy duty shredders and two have heavy duty shredders only.

The trend of reduced extraction is shown in Figure 4 and is one of the most stable of those analysed with an average of 96.65% and a coefficient of variation of 0.20.

The mobile laboratory to evaluate the performance of individual milling tandems and software developed for Cenicaña to model the extraction processes (Carvajal, et al., 2006; Gómez et al., 2003) had contributed to the stabilisation of the reduced extraction.

The extraction efficiency is directly related to changes in the content of industrial fibre % cane. In the period 2002–2006, industrial fibre was 0.13 percentage points higher and the extraction was lower than the values reported in the two year period 2007–2008.

However, the magnitude of the difference in the extraction was higher than that observed due to the fibre increase only. This may be explained in terms of imbibition % cane, which was reduced on average.

The imbibition rate is not always a function of the industrial fibre content as would be expected. Low imbibition rates with high industrial fibre content are reported during rainy periods, while high imbibition rates with low industrial fibre content are reported during dry periods.

This trend would indicate that imbibition is a function not only of the industrial fibre content but also of the availability of steam which is affected by the bagasse quality expressed in terms of moisture and ash content.

![Figure 4](image_url)  
**Fig. 4**—Monthly averages for reduced extraction at 12.5% fibre.

**Boiling house efficiency**

Since 2001, the BHR has shown good stability and higher efficiencies, with only one data point below 90% as illustrated in Figure 5. Since August 2007, the BHR has stabilised around 92% due to the projects undertaken to reduce the undetermined losses.

In 2006, after the installation of the five distilleries for fuel ethanol production and, as a consequence of the different problems in the fermentation, some of them related with the high
content of volatile acidity of the substrate, Cenicaña conducted a project focused on reducing the undetermined losses (Calero et al., 2009).

The pathway followed in the project covered microbiological, physical and chemical analyses from first expressed juice to syrup, critical analysis of the control strategies used for process variables, process residence time, and suggestions for geometry and size of the pans.

This project helped to reduce the drop in purity between first expressed juice and raw juice from 1.9 in 1998 to 1.3 in 2008 and the drop in purity between clear juice and filtrate juice from 2–3 units to 1–2 units in some mills.

From Figure 6, it is clear that, while the determined losses (bagasse, cake and final molasses) remain relatively constant at around 11%, the undetermined loss shows a decreasing trend.

![Graph of boiling house recovery (BHR) in Colombia.](image)

During the 10 year period under review, the industry has also changed the clarifiers. Three mills have the latest generation SRI clarifiers, but RapiDorr and Dorr 444 clarifiers are also used.

The use of continuous vacuum pans has been adopted in four mills; two for B massecuite and two for A massecuite as well as the use of vertical crystallisers in two of the mills.

These changes have contributed to maintaining the pol loss in final molasses relatively constant despite the changes in cane quality due to the increased percentage of cane harvested mechanically. This has increased from an average of 15% in 1998 to 30% in 2008. Two mills are harvesting around 50% mechanically.

In addition to the technological changes, the main results of the projects to reduce the pol loss in final molasses (Gil et al., 2001a) and the determination of target purity in final molasses (Gil et al., 2001b) include:

- the improvement in the slurry preparation;
- a methodology for measuring the crystal size; and
- a methodology to evaluate the exhaustion of C massecuite.

These results have contributed to reduce the pol loss in final molasses from 6.44% pol in cane in 1998 to 5.99% pol in cane in 2005.

After 2005, five of the ten mills stopped producing final molasses and diverted B molasses to ethanol production.
Overall recovery

Overall recovery performance has been stable at values higher than 87% from the middle of 2001 as illustrated in Figure 7.

During the past seven years, OR increased one unit on average in spite of the increasing trash material processed with the cane and the adverse climatic conditions of the last two years.

This improvement in the factory performance represents, for an average crushing year season of 20 millions tonnes of sugarcane, an additional production of 27 000 tonnes of sugar.

Conclusions

The use of standardised monthly inter mill benchmarking has become a valuable tool for the periodic comparative analysis of information among sugar mills and a fundamental tool for continuous improvement of the industry.
During the past ten years, the sustained improvement in sucrose % cane and factory efficiency was excellent. Since 2002, the increase in sucrose content of 0.25 units and in overall recovery of one unit represents an extra production of 69,860 tonnes of sugar for an average season of 20 million tonnes of cane.

Despite the fact that Colombian field productivity is the highest in the world, and is a product of more than 35 years of research on agricultural packages and varietal breeding, the assessment of sugar factory performance is much more recent and the development of the technology is still at an early stage. Using the developed standardised measurement system detailed in this paper, researchers at Cenicana, technicians from the sugar and ethanol factories, consulting enterprises and so on, are able to formulate reliable factory improvement strategies, increase production capacity of the plants as well as periodic benchmarking assessments.

Many opportunities are open to the Colombian sugar sector. First, its important contribution to the ‘National plan for oxygenated gasoline’, which, at July 2009, is covering 85% of the total demand of bioethanol, and the expected demand for increased production capacity in the future. Finally, cogeneration in sugar mills is becoming an interesting business option, after the Colombian Regulatory Committee on energy and gas developed a set of requirements for Colombian agents to obtain the category of electrical generator.

Acknowledgments
The Chiefs of the Departments of Quality and Compliance, laboratory technicians and sugarcane mill factory directors for the support and commitment for keeping the information system standardised and incorporating it as an essential tool for the analysis of the Colombian sugarcane industry.

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UNE ETUDE ANALYTIQUE DE L’EVOLUTION DE LA PERFORMANCE DES SUCRERIES COLOMBIENNES

Par

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MOTS CLEFS: Analyses, des Performances, Revue, Standardisation.

Résumé

En 1993, l'industrie sucrière colombienne a reconnu l'importance de la création d'une fiabilité Standard Mesuring System (SMS) pour les usines a sucre, dans le but de développer des outils pour la gestion. Ce système comprenait l’échantillonnage, les procédures analytiques et des modules de calcul. Il a été généré en conjonction avec des experts du Sugar Research Institut en Australie (Ken Miller et Geoffrey Bentley), le chimiste en chef de chaque usine et le personnel technique de Cenicaña. Depuis janvier 1998, le Factory Process Research Program à Cenicaña, avec le personnel de dix usines colombiennes, a commencé la construction d'une base de données intégrée, en se concentrant sur le registre de 42 variables de processus mesurés ou calculés dans chaque usine. Chaque variable donne par les usines est une moyenne pondérée mensuelle. L’éventail de variables prédéterminés comprend ceux liés à la qualité, bilan saccharose (perte indéterminée), utilisation et efficacité de l’emploi du temps. Parce que le système SMS a un comportement dynamique très fort, un programme parallèle pour évaluer la qualité de l'information a été établi (Calero, et al. 2006). Pendant cette période de 10 ans, l'amélioration du saccharose % canne et de l'efficacité à l’usine est remarquable. Depuis 2002 jusqu'à présent, on trouve une augmentation de 0.25 de saccharose % canne et de 1% en récupération générale (OR) ce qui représentent une production supplémentaire de 69 860 tonnes de sucre pour 20 millions de tonnes de canne par an.
REVISION ANALITICA DE LA EVOLUCION HISTORICA DE ALGUNOS INDICES DE DESEMPEÑO DE LOS INGENIOS AZUCAREROS COLOMBIANOS

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PALABRAS CLAVES: Análisis, Desempeño, Revisión, Estandarización.

Resumen

En 1993, la industria azucarera colombiana reconoció la importancia de crear un sistema confiable de medición estandarizado (SMS) para los ingenios azucareros, con el propósito de desarrollar herramientas para la gestión de procesos. Este sistema incluyó, muestra, procedimientos analíticos, y un módulo de cálculos. Este sistema fue desarrollado con apoyo de expertos del Sugar Research Institute de Australia (Ken Miller y Geoffrey Bentley), los jefes de laboratorio de los ingenios y personal técnico de Cenicaña. Desde 1998, el Programa de Procesos de Fábrica de Cenicaña en conjunto con personal técnico de 10 de los principales ingenios azucareros colombianos, empezaron la construcción de una base de datos, que registra 42 variables de proceso medidas y/o calculadas en cada ingenio. Cada variable reportada por los ingenios está basada sobre promedios ponderados mensuales. Estas variables comprenden aquellas relacionadas con calidad de caña, balance de sacarosa, uso de energía y eficiencia en el uso del tiempo. Debido al carácter dinámico del SMS se estableció un programa paralelo para valorar la calidad de la información reportada. Durante estos primeros 10 años, se destaca el incremento en la sacarosa % caña y las eficiencias en las fábricas. Del año 2002 a la fecha, el incremento en 0.25 unidades en la sacarosa % caña y en una unidad porcentual de la recuperación total (OR) representa una producción adicional de 69 860 toneladas de azúcar para una molienda típica de 20 millones de caña por año.
THE EFFECTS OF CENTRIFUGAL AND FACTORY OPERATION IN COLOUR INCLUDED AND OCCLUDED IN PLANTATION WHITE SUGAR CRYSTALS FOR FIVE FACTORIES OF CENTRAL AMERICA

By

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KEYWORDS: Colour, Included, Occluded, Centrifugal, Wash Water, Mean Aperture.

Abstract

COLOUR is the most widely accepted and possibly the most important quality parameter of white sugar. It is necessary to know what happens in the various stages of the factory operations to determine the colour inside the crystal (included colour) and colour on the crystal surface (occluded colour). Only surface colour is eliminated by wash water in the centrifugals. This study considers the effects of wash water time on the reduction in colour and the loss through dissolution of the sugar crystals in the batch centrifugals, and the analysis of the occluded (surface layer) and included (inside the crystal) colour for different process conditions such as changing the purities of the C and B magma, using different process cationic flocculants and using different washing times in the centrifugals in five sugar factories of Central America. Experimental equations for crystal loss against washing time are studied in three of the factories. Results indicated the impact of using cationic flocculants, syrup clarification and improving boiling purity for strikes for the five factories. The results indicate that crystal colours of 85 to 135 ICUMSA can be obtained when best practice processes are adopted, However, crystal losses of at least 15% can be expected when wash times of more than 20 seconds with 480 kPag water at 85°C to 95°C is used.

Introduction

Colour and impurities

Colour is the most widely accepted and possibly the most important quality parameter of white sugar. It is necessary to know what happens in the various stages of the factory operations to determine the colour inside the crystal (included colour) and colour on the crystal surface (occluded colour). Only surface colour is eliminated by wash water in the centrifugals and that is why, above a certain level, further increase in the amount of wash water does not result in an improvement of the quality of the sugar (Van der Poel et al., 1987).

Colour in white sugar massecuites comes from colour in raw juice, colour formation in heaters, evaporators and clarifiers, colour formation in tanks and pans, type of factory operations and colour recycling from B and C magma.

In crystallisation operations, impurities have a dramatic effect on the habit and crystal size distribution due to the influence on the kinetics of growth and nucleation. Some examples of the impurities in the sugar crystal are (Genck, 1997) colour molecules, inorganic ash compounds, mother liquor located at the surface of the crystal, air and gas bubbles, mother liquor droplets included in the growing crystal lattice, and polysaccharides and oligosaccharides.

A high supersaturation of the mother liquor during boiling promotes fast growth but it also promotes inclusion of impurities within the crystal lattice. Impurities adsorb onto crystal surfaces and influence interfacial tension. Also, impurities are incorporated more easily into large crystals and at high concentrations like at the end of a strike.
Centrifugal process performance

When considering centrifugal performance, it is possible after several assumptions to idealise the flow of the mother liquor (A, B or C molasses) through a sugar cake by considering the flow down a thin pipe. Grimwood (1996) shows that the small gaps which exist between the individual crystals of sugar in the centrifugal basket are proportional to the average size of the crystals or mean aperture (MA). It is possible to write this expression as follows:

\[
\text{Centrifuge performance} = (\text{MA})^2 \times \frac{G \times \Delta t}{(\text{Mother liquor viscosity} \times L)}
\]  

(1)

Where:

- \( \text{MA} \) = Mean aperture of sugar (average size of sugar crystals), \( \mu \text{m} \).
- \( G \) = force pushing syrup through the sugar cake. \( \text{Ft/s}^2 \).
- \( \Delta t \) = Spin time, s.
- \( L \) = Sugar cake thickness, ft.

During acceleration a water wash is normally applied to the sugar. Washes are applied for 5 to 20 seconds depending on the grade of sugar being produced, wash jets and other operational parameters. The application of wash water has two main beneficial effects, first to increase the purity of the sugar and, secondly, to reduce its final moisture.

As the wash water flows through the cake, it becomes saturated with sugar after the first 50–75 mm and this saturated solution displaces the massecuite mother liquor (Grimwood, 1996). However, washing has the unwanted effect of melting (dissolving) a proportion of the sugar.

According to Grimwood (1996), there are three washing mechanisms that take place in the centrifuge: displacement, diffusion and dissolution.

In displacement wash, the mother liquor filling the gaps between the crystals is displaced by wash liquor; in diffusion wash, dissolved material in the remaining mother liquor adhering to the crystals is transferred (diffuses) into the wash liquor, and in dissolution wash, the surface layers of the crystals are dissolved by the wash liquor.

Methods

Crystal loss

The real amount of crystal sugar that is dissolved in the wash water and ends up in the syrup can be determined by measuring the sugar cake thickness for different wash times, including no washing as the base case for a specific batch centrifuge, strike and factory. Different amounts of wash water were applied for a specific centrifuge in two factories.

For zero or low washing times, the measurements can be taken before the centrifugal is returned to the normal cycle to achieve the desired sugar quality. The temperature and pressure of the wash water was also recorded.

Included colour

It was decided to limit wash water use to a maximum of 25 s because available data show that additional wash water did not improve the quality of the sugar. Further improvement in quality could be achieved with changes to other process conditions such as changing the purity of C magma and B magma, seeding for A strikes, using different process cationic flocculants or colour precipitants, syrup clarification and improving the boiling purity for A strikes for different sugar factories.

Qemitreat SEP (from Qemi International Inc.) decolourant usage was set at 40 ppm on solids. The polymer was diluted 1:1 with water and added to the clear juice tank.

Colour elimination

The colour remaining in the sugar crystal at the end of the cycle can be determined as a function of wash time. For no washing or low washing times, a sample of sugar was taken before the normal cycle was resumed to obtain the desired sugar quality.
Results and discussion

Trials were conducted at five factories to measure the effects on the sugar product from the application of different process conditions, with and without syrup clarification and with and without the use of colour precipitant. The centrifugals used during the trials are listed in Table 1.

<table>
<thead>
<tr>
<th>Factory</th>
<th>Centrifugal brand</th>
<th>Basket size (in mm)</th>
<th>Wash water supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Western States</td>
<td>54 x 40 (1370 x 1016)</td>
<td>480</td>
</tr>
<tr>
<td>C</td>
<td>Western States</td>
<td>48 x 36 (1219 x 914)</td>
<td>550</td>
</tr>
<tr>
<td>D</td>
<td>Western States</td>
<td>48 x 30 (1219 x 762)</td>
<td>550</td>
</tr>
</tbody>
</table>

Figure 1 illustrates the degree of crystal loss as a function of wash water usage for the Western States centrifugals at factories B, C and D. The centrifugal used at factory B was working at 1020 G. The collected data for factory B represent the averages of 87 separate measurements. The data show a crystal loss of 11.8% when wash water was applied for 20 seconds.

For factory C, the collected data correspond to the averages of 90 measurements. A crystal loss of 15.5% is reported when 20 s of wash water is applied. Factory D has the smallest centrifugal of the three units tested. The collected data correspond to the average of 50 measurements and show a crystal loss above 20% at 20 s of wash water application.

These three trends in Figure 1 show just how much sugar is dissolved when excessive quantities of wash water are used in the centrifugals to achieve low colour sugar.

Figure 2 illustrates how much colour is removed as a function of wash water usage for the same Factory B centrifugal and conditions of Figure 1. It can be seen that, after about 20 s, further
increases in the amount of wash water do not result in any improvement in the quality of sugar in terms of colour. A colour ratio can be defined and represents the colour remaining in the sugar as a ratio of the original colour before any wash water is applied. Thus, after 20 s of wash, the colour remaining is about 16.6% and, after 25 s of wash, the remaining colour is about 10.6% of the original colour. However, the extra 5 s of wash dissolved another 2.3% of the crystal according to the data in Figure 1.

\[
y = 1265.8 e^{-0.0896x} \\
R^2 = 0.9114
\]

![Fig. 2—Final sugar colour as a function of wash water time for factory B. (Western States centrifugal, 54 x 40, 480 kPag, 85–95°C).](image1)

For factory C, the colour elimination curves as a function of water and cationic flocculant (at 40 ppm on solids) usage are shown in Figure 3 and Table 2. When using cationic flocculant, the sugar colour was about 28% lower than the sugar colour produced without the use of the cationic flocculant. This means that less wash water is required to achieve a certain sugar colour if cationic flocculant is used. For example, if 20 s of wash is required to achieve the required colour without flocculant, then the same colour can be achieved with only 17 s of wash if cationic flocculant had been used in the process and 3% less crystal would have been dissolved in the centrifugals.

![Fig. 3—Final sugar colour as a function of wash water time for factory C (Western States centrifugal, 48x36, 550 kPag, 80–90°C).](image2)
Table 2—Sugar colour results for factory C.

<table>
<thead>
<tr>
<th>Wash time (s)</th>
<th>0</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar colour after using cationic flocculant</td>
<td>1778</td>
<td>1010</td>
<td>269</td>
<td>240</td>
<td>188</td>
</tr>
<tr>
<td>Sugar colour without using cationic flocculant</td>
<td>2605</td>
<td>1480</td>
<td>390</td>
<td>326</td>
<td>235</td>
</tr>
<tr>
<td>Colour ratio with cationic flocculant</td>
<td>100.0%</td>
<td>56.8%</td>
<td>15.1%</td>
<td>13.5%</td>
<td>10.6%</td>
</tr>
<tr>
<td>Colour ratio without cationic flocculant</td>
<td>100.0%</td>
<td>56.8%</td>
<td>15.0%</td>
<td>12.5%</td>
<td>9.0%</td>
</tr>
<tr>
<td>Colour reduction due to use of colour precipitant</td>
<td>31.7%</td>
<td>31.8%</td>
<td>31.0%</td>
<td>26.4%</td>
<td>20.0%</td>
</tr>
<tr>
<td>Average colour reduction</td>
<td>28.2%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3 shows the included colour data collected from five sugar mills and some variations of the processes involved. The best practice is to achieve low impurity concentrations in mother syrup to minimise the probability of including impurities in the growing crystal. This can be done by improving the B and C magma purities, using syrup clarification, using cationic flocculants or decolourants and seeding for A strikes. Factory E has produced a low colour sugar but with the disadvantage of the impact in sucrose recovery and the extra recirculation load in the boiling scheme. This factory sells its sugar to a market that pays a special price for the quality. The benefit of using cationic flocculants is that some colourants are removed from the syrup before going to the boiling house. The key variables for improving sugar quality after syrup clarification are the target purities of C and B magma, due to the colour impact on the A strikes. As seen in Table 3, the crystal sugar process which uses only the juice from the first mill results in a high quality sugar product. The double magma boiling scheme uses seeding for C strikes and uses C magma as a footing for B strikes and B magma as the footing for A strikes.

Table 3—Crystal (included) colour after 25 s of wash water at five mills with different process conditions.

<table>
<thead>
<tr>
<th>Factory</th>
<th>Process</th>
<th>Syrup clarif.</th>
<th>Cationic loc.</th>
<th>Magma purity</th>
<th>Included colour (IU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Strikes using syrup from first mill juice</td>
<td>No</td>
<td>No</td>
<td>n.a.</td>
<td>92</td>
</tr>
<tr>
<td></td>
<td>(crystal sugar process)</td>
<td></td>
<td></td>
<td>n.a.</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Double magma boiling scheme</td>
<td>Yes</td>
<td>No</td>
<td>n.a.</td>
<td>183</td>
</tr>
<tr>
<td>C</td>
<td>Double magma boiling scheme</td>
<td>Yes</td>
<td>No</td>
<td>n.a.</td>
<td>220</td>
</tr>
<tr>
<td>B</td>
<td>Double magma boiling scheme</td>
<td>Yes</td>
<td>Yes</td>
<td>n.a.</td>
<td>123</td>
</tr>
<tr>
<td>C</td>
<td>Double magma boiling scheme</td>
<td>Yes</td>
<td>Yes</td>
<td>n.a.</td>
<td>177</td>
</tr>
<tr>
<td>C</td>
<td>Direct crystallisation, A strike seeding</td>
<td>Yes</td>
<td>Yes</td>
<td>97</td>
<td>135</td>
</tr>
<tr>
<td>D</td>
<td>Double magma boiling scheme</td>
<td>Yes</td>
<td>Yes</td>
<td>97</td>
<td>125</td>
</tr>
<tr>
<td>D</td>
<td>Double magma boiling scheme</td>
<td>Yes</td>
<td>Yes</td>
<td>97</td>
<td>160</td>
</tr>
<tr>
<td>E</td>
<td>Strike of syrup with melted B magma</td>
<td>Yes</td>
<td>Yes</td>
<td>n.a.</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>Double magma boiling scheme</td>
<td>Yes</td>
<td>Yes</td>
<td>98.5</td>
<td>90</td>
</tr>
</tbody>
</table>

n.a. = not available

Another process variation, where tanks and pans are available, is to process special strikes using melted B magma (for the best sugar quality), and melted C magma and syrup for the other commercial strikes.

Cane quality has a dramatic effect on sugar quality and included colour. The presence of vegetable and mineral trash, time delay, harvesting systems and cane deterioration, are key factors for a good crystallisation operation because impurities are incorporated more easily at high concentrations. Impurities like polysaccharides, oligosaccharides and other macromolecules that are related to cane quality influence sugar processing and have been implicated in the inclusion of colour in crystals. They also influence the mother liquor viscosity that also affects centrifugal performance.
Conclusions

It is important to determine experimental relationships for crystal loss and sugar colour against wash time for a specific model of batch centrifugal and the material being processed at a factory. The crystal loss of the three factories and centrifugals discussed in this paper varies from 11% to more than 20% with 20 s of wash time.

For factory C, the results show that, by using the same wash time, sugar with 28% less colour is achieved when colour precipitant is used as part of the syrup clarification process.

The key variables after a good syrup clarification and cane quality for improving sugar quality are the target purities of C and B magma.

REFERENCES


EFECTOS DE CENTRÍFUGAS Y LA OPERACIÓN FABRIL EN EL COLOR INCLUIDO Y OCLUIDO EN CRISTALES DE AZÚCAR BLANCO EN CINCO INGENIOS CENTROAMERICANOS

Por

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PALABRAS CLAVE: Color, Incluido, Ocluido, Centrífuga, Agua de Lavado, Apertura Media.

Resumen

EL COLOR es el parámetro de calidad del azúcar blanco más aceptado universalmente y posiblemente el más importante. Se requiere conocer lo que sucede en las varias etapas operativas de la fábrica para determinar el color dentro del cristal (color incluido) y el color en la superficie del cristal (color ocluido). Solamente el color superficial es removido por el lavado en las centrífugas. Este estudio considera los efectos del tiempo de lavado en la reducción de color y la pérdida por disolución de cristales en las centrífugas de batch y el análisis de color incluido y ocluido para diferentes condiciones de proceso tales como purezas variables en magma C y B, uso de diferentes floculantes catiónicos y el uso de diferentes tiempos de lavado en las centrífugas de cinco ingenios centroamericanos. Se estudiaron las ecuaciones experimentales para la pérdida de cristales contra tiempo de lavado en tres de los ingenios. Los resultados muestran el impacto del uso de los floculantes catiónicos, la clarificación de meladura y el mejoramiento de la pureza de las templas para las cinco fábricas. Cuando las mejores prácticas se adoptan, pueden obtenerse colores de cristal de 85 a 135 ICUMSA; sin embargo, pueden esperarse pérdidas de cristal de al menos 15% cuando se emplean tiempos de lavado mayores a 20 s con agua a 480 kPag y 85°C a 95°C.
PROGRESS IN IMPROVING LABORATORY EFFICIENCIES USING NEAR INFRARED SPECTROSCOPY (NIRS)

By

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KEYWORDS: NIRS, Molasses, Massecuites, Syrup, Clear Juice.

Abstract

The laboratories of the Sugar Milling Research Institute have the responsibility of maintaining and improving the standards of analytical work within the SMRI and throughout the Southern African sugar industry. Based on development work conducted by the SMRI, the use of NIR spectroscopy has been approved for the analysis of C molasses for both factory control and cane payment purposes and has resulted in considerable savings in analytical costs. Development work is ongoing and samples of clear juice, syrup, B, C massecuite and A, B molasses have been analysed by traditional methods for sucrose, pol and brix, and the results used to develop NIRS calibrations for rapid multi-component analysis. The precision of the NIRS predictions appears to be excellent, comparable to the laboratory method tolerances, and it is suggested that this technology can be used by relatively unskilled personnel in a factory environment to produce reliable data at relatively low cost.

Introduction

The major sugar companies of South Africa have been expanding their operations in the Southern African sugar industry. The laboratories of the Sugar Milling Research Institute (SMRI) provide analytical services to the region and, with increased demand, it has been appropriate to develop near infrared spectroscopy (NIRS) methods for the rapid multi-component analysis of intermediate factory products.

Much of the earlier work at the SMRI was reported by Schäffler and De Gaye (1997) and Schäffler (2005) and was based on work initiated at CSM Suiker (de Bruijn, 1997).

A Foss NIR Systems 5000 spectrometer was used to acquire spectra but was prone to bias jumps and required adjustment, updating the calibration dataset and standardisation as the instrument was aging.

In the 2007–2008 season, the SMRI purchased a Bruker Near Infra-red Spectrometer and interfaced this with a Metrohm 838 auto sampler. No calibration modification was required when a major component such as a source lamp was replaced unlike previous experiences by Schäffler (2000).

Calibrations were developed for molasses and mixed juice and the comparison with earlier work was reported by Simpson and Oxley (2008). The NIRS analysis of molasses has subsequently been adopted for cane payment purposes by the South African sugar industry.

The implementation of NIRS analysis for molasses at the SMRI has resulted in major time and cost savings.

This coupled with the desire to provide analysis for factory control purposes performed by relatively unskilled laboratory staff has extended the scope of calibration development to include additional intermediate products and this work is the subject of this paper.
Experimental

Instrumental: Near Infra Red Spectrometer (NIRS)

The NIRS system is comprised of a Bruker Multi-purpose Analyser (MPA) fitted with a Metrohm 838 autosampler. No temperature control unit was attached to the MPA. However, the NIRS laboratory was maintained at 20°C by air-conditioning at all times.

All spectra were obtained in absorbance mode in the scanning range 800 to 2500 nm using a Hellma flow-through sample cell with a path length of 1 mm. The NIRS software used for spectral processing and calibration creation was OPUS Version 6.

This included Opus Lab, which provided a simple interface with mouse-click operations for controlling automated NIRS analysis. This interface was used throughout for sample analysis.

Samples

The 2008–2009 season weekly composite samples of clear juice, syrup, B, C massecuite and A, B molasses were sent to the SMRI from five different geographically located Southern African sugar factories viz. Malalane (ML), Felixton (FX), Noodsberg (NB), Nakambala (NK), Umzimkulu (UK). These samples were analysed for sucrose, pol (lead clarified) and brix.

Handling of clear juice and syrup samples

Weekly factory composites of clear juice and syrup samples submitted to the SMRI were analysed by NIRS. Syrup samples were diluted at 50 grams to 200 grams of which 150 grams was lead clarified for pol and the remaining 50 grams was filtered for brix. A 5 gram portion of syrup was diluted to 30 grams and analysed by gas chromatography (GC) for sucrose.

In addition, an unfiltered portion of the clear juice composite was submitted to the NIRS laboratory. Syrup samples were diluted at 20 g to 100 cm$^3$ for NIRS analyses. Each sample was analysed in triplicate and a NIRS spectrum for each obtained using Opus Lab. The predicted results from the three spectra were averaged to give the final predicted NIRS results.

All laboratory results were generated using the Official Methods (Anon, 1985 and 2005). Pol was measured on the Schmidt & Haensch Universal Polartronic using the wavelength 589 nm and lead clarification (Anon., 2005: Method 1.7). Brix was measured by refractometry. Sucrose was determined by gas chromatography (silylation-only) method (Anon., 2005: Method 1.9).

Handling of B, C massecuite and A, B molasses

Weekly composite samples of B, C massecuite and A, B molasses samples submitted to the SMRI were manually homogenised and sub-sampled. A single sub-sample was used for all test methods and the NIRS sample preparation. The samples were clarified and filtered for pol and brix analyses (Anon., 1985).

The massecuite and molasses samples were diluted and tested for fructose, glucose and sucrose by high performance anion exchange chromatography (Anon., 2005: Method 6.6). B massecuite was diluted at 14.5 grams to 100 cm$^3$ and C massecuite was diluted at 14 grams to 100 cm$^3$.

Each prepared sample was analysed in triplicate and a NIRS spectrum was obtained for each. The predicted results from the three spectra were averaged to give the final predicted NIRS results.

A quality control procedure was set up using three molasses samples of established composition with each batch of samples tested.

These were used to monitor the NIRS performance on a weekly basis. All laboratory results were generated using SASTA approved test methods (Anon., 2005). Polartronic measurements were made using the wavelength 589 nm and lead clarification (Anon., 2005: Method 6.1).

Brix was measured by refractometry in all cases (Anon., 2005: Method 6.1). Sucrose was determined by high performance anion exchange chromatography (Anon., 2005: Method 6.6).
Calibrations

Calibrations for C molasses were done with Bruker’s *OPUS QUANT* Software. This software uses multivariate data analysis to combine a large amount of spectral information with the corresponding reference values. Partial least squares (PLS) regressions were used to draw up the calibrations.

A calibration model was built using 50% calibration samples and 50% of the test samples were used to validate the model. Where the number of samples was less than 300, the method of cross validation was used to develop the equations. Spectra were added to the initial calibrations during the course of the season to make the models more robust.

Results and discussion

The cross validation results for clear juice, syrup, B, C massecuite and A, B molasses, presented in Tables 2 to 7 (Appendix A) show the correlation between laboratory and NIRS results for pol, brix and sucrose.

The prediction data are summarised in Table 1. The data from Tables 2 to 7 are presented graphically for sucrose in Figures 1 to 6, and the regression lines, slopes and 95% certainty limits for the respective analyses are given.

The results for sucrose were chosen to illustrate data as NIR prediction results for HPLC and GC analytical techniques are often not easy to reproduce with the required accuracy for payment purposes. The prediction data for clear juice gave excellent precision results as all three analyses produced a SEP of better than 0.08 units.

Excellent precision results were achieved for syrup pol and brix (SEP of 0.14 and 0.11, respectively). The RSQ of 0.995 for sucrose was most acceptable. Most products showed good overall predictions (SEP 0.02 to 0.45).

The tables in Appendix B illustrate excellent slope, bias and correlation coefficient squared (RSQ) statistics for the three components.

RSQ results were most acceptable (0.91 to 1.00). Comparing the standard error of prediction (SEP) to the precision of the laboratory method is a measure of the NIRS predictive capability and in all cases was found to be adequate for factory control purposes.

<table>
<thead>
<tr>
<th>Table 1—Prediction results for pol, brix and sucrose.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>------------------------</td>
</tr>
<tr>
<td><strong>RSQ</strong></td>
</tr>
<tr>
<td>Clear juice</td>
</tr>
<tr>
<td>Syrup</td>
</tr>
<tr>
<td>A Molasses</td>
</tr>
<tr>
<td>B Molasses</td>
</tr>
<tr>
<td>B Massecuite</td>
</tr>
<tr>
<td>C Massecuite</td>
</tr>
<tr>
<td><strong>SEP</strong></td>
</tr>
<tr>
<td>Clear juice</td>
</tr>
<tr>
<td>Syrup</td>
</tr>
<tr>
<td>A Molasses</td>
</tr>
<tr>
<td>B Molasses</td>
</tr>
<tr>
<td>B Massecuite</td>
</tr>
<tr>
<td>C Massecuite</td>
</tr>
</tbody>
</table>

SEP = standard error of prediction, RSQ = correlation coefficient squared
Fig. 1—Conventional laboratory method and NIRS correlation for sucrose in clear juice.

Fig. 2—Conventional laboratory method and NIRS correlation for sucrose in syrup.

Fig. 3—Conventional laboratory method and NIRS correlation for sucrose in A molasses.
B MOLASSES SUCROSE - All Samples

\[ y = 0.988x + 0.5231 \]
\[ R^2 = 0.985 \]
\[ SEP = 0.31 \]
\[ 95\% \text{LIMITS} \pm 0.87 \]

Lab Sucrose (%)

NIRS Sucrose (%)

35 40 45 50 55 60

Fig. 4—Conventional laboratory method and NIRS correlation for sucrose in B molasses.

B MASSECUITE SUCROSE - All Samples

\[ y = 0.9185x + 5.6697 \]
\[ R^2 = 0.927 \]
\[ SEP = 0.45 \]
\[ 95\% \text{LIMITS} \pm 1.27 \]

Lab Sucrose (%)

NIRS Sucrose (%)

60 62 64 66 68 70 72 74 76 78 80

Fig. 5—Conventional laboratory method and NIRS correlation for sucrose in B massecuite.

C Massecuite Sucrose - All Samples

\[ y = 0.9143x + 4.9338 \]
\[ R^2 = 0.9515 \]
\[ SEP = 0.29 \]
\[ 95\% \text{LIMITS} \pm 0.81 \]

Lab Sucrose (%)

NIRS Sucrose (%)

50 55 60 65 70

Fig. 6—Conventional laboratory method and NIRS correlation for sucrose in C massecuite.
Future work
- Develop fructose and glucose calibrations for all intermediate factory products.
- Improve the A massecuite sample preparation to develop better correlations.
- Install the NIRS at a mill laboratory with the SMRI universal calibration. This equation would need to be adjusted for local conditions to avoid any bias and maintain the 95% confidence limits with weekly quality control checks. These checks would be based on samples with the conventionally established composition.
- Develop a proposal for implementing the NIRS in a factory laboratory for assessment on the economic impact and the potential for online use. Investigate a ‘master-slave’ relationship between the SMRI and the mills as an option to maintain and update calibrations.

Conclusions
The implementation of routine mixed juice and molasses analysis by NIRS is expected to reduce the time spent by the SMRI laboratory analysts by 80 percent i.e. from 128 hours per week to 24 hours per week and has already been implemented for final molasses at the SMRI. However, factory process managers will also benefit immensely from reliable data produced in a fraction of the time taken for conventional analysis. This work shows that calibrations can be developed for a number of intermediate factory products. The maintenance of the calibrations would require technically competent individuals but routine analysis could be done by relatively unskilled personnel. Due to the geographical location of the mill laboratories, the transportation of samples, particularly those that deteriorate is problematic and expensive. Provided that the mill laboratory has a NIR spectrophotometer, samples could be scanned and spectra sent to the SMRI for interpretation of the results, if technically competent staff are not initially available.

Results would then be returned to the mill laboratory via the internet. With the development of sucrose calibrations, factories could convert from pol to sucrose based performance/payment calculations without costly and complex GC or HPAEC analytical requirements. It would also allow benchmarking based on sucrose for the entire region and not only the South African mills.

Acknowledgements
Thanks are due to the SMRI analytical staff and their efforts in sample co-ordination, scanning, and simultaneous data collection. The continued support and assistance of Bruker South Africa, in calibration management and improvement, is gratefully acknowledged.

REFERENCES
## Appendix A

### Table 2—Clear juice pol, brix and sucrose correlations.

<table>
<thead>
<tr>
<th></th>
<th>Pol</th>
<th>Brix</th>
<th>Sucrose</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of samples</td>
<td>256</td>
<td>242</td>
<td>396</td>
</tr>
<tr>
<td>Slope</td>
<td>0.997</td>
<td>1.000</td>
<td>0.998</td>
</tr>
<tr>
<td>RSQ</td>
<td>0.996</td>
<td>1.000</td>
<td>0.997</td>
</tr>
<tr>
<td>Bias</td>
<td>0.000</td>
<td>0.000</td>
<td>0.002</td>
</tr>
<tr>
<td>Range</td>
<td>0.081</td>
<td>−0.088</td>
<td>−0.370</td>
</tr>
<tr>
<td>SEP</td>
<td>0.082</td>
<td>0.021</td>
<td>0.066</td>
</tr>
</tbody>
</table>

SEP = standard error of prediction, RSQ = correlation coefficient squared

### Table 3—Syrup pol, brix and sucrose correlations.

<table>
<thead>
<tr>
<th></th>
<th>Pol</th>
<th>Brix</th>
<th>Sucrose</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of samples</td>
<td>295</td>
<td>313</td>
<td>229</td>
</tr>
<tr>
<td>Slope</td>
<td>0.998</td>
<td>0.999</td>
<td>0.996</td>
</tr>
<tr>
<td>RSQ</td>
<td>0.998</td>
<td>0.998</td>
<td>0.995</td>
</tr>
<tr>
<td>Bias</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Range</td>
<td>−0.470</td>
<td>−0.050</td>
<td>−0.670</td>
</tr>
<tr>
<td>SEP</td>
<td>0.139</td>
<td>0.112</td>
<td>0.214</td>
</tr>
</tbody>
</table>

SEP = standard error of prediction, RSQ = correlation coefficient squared

### Table 4—A molasses pol, brix and sucrose correlations.

<table>
<thead>
<tr>
<th></th>
<th>Pol</th>
<th>Brix</th>
<th>Sucrose</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of samples</td>
<td>298</td>
<td>300</td>
<td>79</td>
</tr>
<tr>
<td>Slope</td>
<td>0.988</td>
<td>0.954</td>
<td>0.985</td>
</tr>
<tr>
<td>RSQ</td>
<td>0.990</td>
<td>0.950</td>
<td>0.985</td>
</tr>
<tr>
<td>Bias</td>
<td>0.002</td>
<td>−0.002</td>
<td>0.009</td>
</tr>
<tr>
<td>Range</td>
<td>0.560</td>
<td>−1.090</td>
<td>−0.880</td>
</tr>
<tr>
<td>SEP</td>
<td>0.225</td>
<td>0.220</td>
<td>0.323</td>
</tr>
</tbody>
</table>

SEP = standard error of prediction, RSQ = correlation coefficient squared

### Table 5—B molasses pol, brix and sucrose correlations.

<table>
<thead>
<tr>
<th></th>
<th>Pol</th>
<th>Brix</th>
<th>Sucrose</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of samples</td>
<td>294</td>
<td>293</td>
<td>116</td>
</tr>
<tr>
<td>Slope</td>
<td>0.937</td>
<td>0.992</td>
<td>0.988</td>
</tr>
<tr>
<td>RSQ</td>
<td>0.937</td>
<td>0.991</td>
<td>0.985</td>
</tr>
<tr>
<td>Bias</td>
<td>0.022</td>
<td>0.000</td>
<td>−0.007</td>
</tr>
<tr>
<td>Range</td>
<td>−4.770</td>
<td>−0.640</td>
<td>−0.950</td>
</tr>
<tr>
<td>SEP</td>
<td>1.249</td>
<td>0.225</td>
<td>0.308</td>
</tr>
</tbody>
</table>

SEP = standard error of prediction, RSQ = correlation coefficient squared
### Table 6—B massecuite pol, brix and sucrose correlations.

<table>
<thead>
<tr>
<th>B massecuite</th>
<th>Pol</th>
<th>Brix</th>
<th>Sucrose</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of samples</td>
<td>289</td>
<td>293</td>
<td>110</td>
</tr>
<tr>
<td>Slope</td>
<td>0.987</td>
<td>0.934</td>
<td>0.919</td>
</tr>
<tr>
<td>RSQ</td>
<td>0.986</td>
<td>0.949</td>
<td>0.927</td>
</tr>
<tr>
<td>Bias</td>
<td>−0.002</td>
<td>−0.005</td>
<td>−0.008</td>
</tr>
<tr>
<td>Range</td>
<td>−0.120</td>
<td>0.190</td>
<td>3.470</td>
</tr>
<tr>
<td>SEP</td>
<td>0.221</td>
<td>0.152</td>
<td>0.447</td>
</tr>
</tbody>
</table>

SEP = standard error of prediction, RSQ = correlation coefficient squared

### Table 7—C massecuite pol, brix and sucrose correlations.

<table>
<thead>
<tr>
<th>C massecuite</th>
<th>Pol</th>
<th>Brix</th>
<th>Sucrose</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of samples</td>
<td>229</td>
<td>257</td>
<td>85</td>
</tr>
<tr>
<td>Slope</td>
<td>0.990</td>
<td>0.904</td>
<td>0.914</td>
</tr>
<tr>
<td>RSQ</td>
<td>0.989</td>
<td>0.910</td>
<td>0.952</td>
</tr>
<tr>
<td>Bias</td>
<td>0.000</td>
<td>0.001</td>
<td>0.014</td>
</tr>
<tr>
<td>Range</td>
<td>0.090</td>
<td>0.050</td>
<td>1.110</td>
</tr>
<tr>
<td>SEP</td>
<td>0.170</td>
<td>0.170</td>
<td>0.288</td>
</tr>
</tbody>
</table>

SEP = standard error of prediction, RSQ = correlation coefficient squared

AMÉLIORATION DE L’EFFICACITÉ AU LABORATOIRE À L’AIDE DE LA SPECTROSCOPIE INFRAROUGE PROCHE (NIRS)

Par
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MOTS-CLEFS: NIRS, Mélasse, Massecuites, Sirop, Jus Clarifié.

Résumé
Les laboratoires du Sugar Milling Research Institute ont la responsabilité de maintenir et améliorer les normes du travail analytique au sein du SMRI et dans les industries sucrières du sud de l’Afrique. Un travail de développement mené par le SMRI a permis l'utilisation du NIRS pour l'analyse de la mélasse C pour le contrôle en usine et pour le paiement de la canne; ceci a donné des économies considérables dans les coûts d'analyse. Le travail de développement continu; des échantillons de jus clarifié, sirop, massecuites B et C, et mélasses A et B ont été analysés par les méthodes traditionnelles pour déterminer le saccharose, le pol et le Brix; les résultats ont été utilisés pour développer des étalonnages pour le NIRS, donnant ainsi des analyses multiples rapidement. La précision des résultats du NIRS semble être excellente; elle est comparable à la précision des méthodes conventionnelles de laboratoire. On suggère que cette technologie peut servir pour un personnel relativement non qualifié dans un environnement d’usine, pour produire des résultats fiables à coût relativement faible.
PROGRESOS EN EL MEJORAMIENTO DE LAS EFICIENCIAS DE LABORATORIO CON EL USO DE ESPECTROSCOPÍA DE INFRAROJO CERCANO (NIRS)

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PALABRAS CLAVE: NIRS, Mieles, Masas Cocidas, Meladura, Jugo Clarificado.

Resumen

LOS LABORATORIOS del SMRI (Sugar Milling Research Institute) tienen la responsabilidad de mantener y mejorar los estándares del trabajo analítico dentro del Instituto y en toda la industria azucarera sudafricana. Con base en trabajo de desarrollo dirigido por el SMRI, el uso de espectroscopía NIR ha sido aprobado para el análisis de mieles C tanto para control fabril como para fines de pago de caña y ha generado considerables ahorros en costos de análisis. El trabajo continúa y muestras de jugo clarificado, meladura, masas B, C, y mieles A y B se han analizado con métodos tradicionales para sacarosa, pol y brix y los resultados se usaron para generar calibraciones de NIRS para análisis rápido multi-componente. La precisión de las predicciones del NIRS fue excelente, comparable a las tolerancias del método de laboratorio y sugirió que esta tecnología puede ser usada por personal relativamente inexperto en un ambiente fabril para producir datos confiables a un costo relativamente bajo.
NEW IDEAS FOR IMPROVING EFFICIENCY IN THE PACKAGING AREA

By

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KEYWORDS: Packaging Area, Overs Screening, Overs and Fines Screening, Overs Milling, Conveying of Sugars.

Abstract
LOOKING for more efficiency in the packaging area where the final product is handled, the performance of different machines for screening was studied, conveying the final product and also the milling of the overs separated by screening. In making the study of these unit operations, information was collected in different sugar mills and the different alternatives for screening the sugar were compared. A higher efficiency was achieved by using a gyratory reciprocating screener and losses of between 1 and 3% of the on-spec sugar were avoided when compared with the performance of other technologies for this operation. The possibility of milling the overs obtained in the screening process was also studied and compared with the traditional dissolution of this material. A milling test was conducted using plantation and refined sugar and 10–20% of the sugar that would normally dissolve and goes to molasses was recovered. Finally, some results obtained in conveying using vibrating conveyors as opposed to screw conveyors are discussed. It was found that recoveries of sugar between 0.5–3.0% were obtained with vibratory conveyors, as opposed to belt conveyors. In the case of screw conveyors, degradation in the order of 1–3% of the size was found. It is concluded that there is an opportunity for the technologist to recover more sugar in this area using the most efficient technology.

Introduction
For many reasons related to the constant increase in capacity of the sugar mills in the Mexican sugar industry and in other countries, the factories have shown a preference to make investments to lower energy consumption and in process equipment like centrifugals, crystallisers, vacuum pans, etc.

This situation has postponed for years projects in the sugar packaging area, and only in the last decade with the increased requirements of the customer concerning the final product and the reprocessing of sugar has the packaging area been looked at (Urrutia, 2000; Mathlouthi and Roge, 2004; Hartmut and Burkhards, 2008; Reichling, 2008).

To improve the particle size distribution it is necessary to reduce the overs and fines in the sugar especially the fines that can cause hardening (Lu et al., 1977). An efficient screener with gyratory-straight line motion offers a more efficient separation and low maintenance cost system for the sugar industry (Bergerhoff, 2006; Thouvard, 2006).

In analysing this situation, the packaging area of the plant could be a real opportunity to improve the plant efficiency.

Materials and methods
Screening of overs
Samples were taken in different sugar mills where various technologies were being used to screen the sugar before packaging. The machines being used were as follows:
• A static screen positioned at the end of the drum dryer.
• A high slope vibratory machine positioned at the dryer discharge.
• Other vibratory machines that were circular, flat or rectangular with an angle of 30° to the horizontal and positioned at the dryer discharge.
• Machines with gyratory motion at the feed end and straight-line motion at the discharge end with a little slope and low frequency motion and positioned at the dryer discharge.

In all cases, three samples were taken at the overs outlet during an hour of stable operation and then composited. The composite was then subdivided into three portions and analysed using a laboratory sieve machine and a 10 mesh (1.7 mm) screen.

**Screening of overs and fines**

Samples were taken in the non-screened inlet and the product outlet at Ingenio Tres Valles and Ingenio El Potrero where high efficiency screeners are used on the dryer outlet to eliminate the overs (>20 mesh, 0.85 mm) and fines (<80 mesh, 0.18 mm). In both cases, the machines have gyratory motion at the feed inlet and straight-line motion at the discharge end with a little slope and low frequency motion.

**Milling of overs**

During these tests, samples were collected at the overs outlet screener in two sugar mills where one mill produces refined sugar and the other plantation sugar. In both cases, the machines use gyratory motion at the feed inlet and straight-line motion at the discharge end with a little slope and low frequency motion.

A milling test was conducted with a Pin Mill model Simpactor 3B equipped with an 11 kW motor and operated at 1000 r/min for refined sugar and 2000 r/min for the plantation sugar samples.

**Sugar conveying**

**Belt conveyor**

In this case, data were collected from three factories by weighing the amount of sugar collected from the floor that had been spilt by the conveyors.

**Screw and vibratory conveyors**

Sugar samples were collected at two sugar mills from the inlet and exit of a 10 m long screw conveyor. Samples collected every 10 minutes for one hour were composited and sub-sampled. The samples were then sieved through a 70 mesh (0.212 mm) sieve. Similar samples were collected from 10 m vibratory conveyors at two other sugar mills.

**Results and discussion**

**Screening to separate the overs**

In the case of the screening to eliminate the overs, we collected the sugar retained in 10 mesh screen in several different sugar factories that used different screeners and we measured the fraction passing at 10 mesh screen that represents on-spec sugar that was retained or lost with the overs. Results of the sieve analyses for the three different machine types are shown in Table 1. The data are the proportion of on-spec sugar removed with the overs portion in relation to the total screened sugar.

<table>
<thead>
<tr>
<th>Screener type</th>
<th>Sugar mill</th>
<th>Weight of on-spec sugar dissolved in a crop (t)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed static</td>
<td>2.3 4.0 3.5 3.2</td>
<td>103.7</td>
</tr>
<tr>
<td>Vibratory</td>
<td>1.2 2.5 2.0 2.6 2.1</td>
<td>67.9</td>
</tr>
<tr>
<td>Gyroratory reciprocating motion, low frequency</td>
<td>0 0 0.1 0 0</td>
<td>&lt; 0.1</td>
</tr>
</tbody>
</table>

* Note: Assumes a factory with 50 t/h sugar and an overs fraction of 1.5%.
Table 2 shows that the investment could be recovered in less than one crop for a factory with a minimum output of 50 t/h of sugar. In the case of factories that produce 20 t/h, the investment is recovered in 1.3 crops. To replace an existing fixed static screen, the recovery of the investment is faster.

<table>
<thead>
<tr>
<th>Capacity (t/h)</th>
<th>On-spec sugar dissolved in one crop period (t)</th>
<th>Cost of the high efficiency machine (USD)</th>
<th>Time to recover the investment of high efficiency screen *</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>27.2</td>
<td>17 299</td>
<td>1.3 crops</td>
</tr>
<tr>
<td>50</td>
<td>67.9</td>
<td>28 722</td>
<td>0.85 crops</td>
</tr>
<tr>
<td>100</td>
<td>102.9</td>
<td>39 518</td>
<td>0.77 crops</td>
</tr>
</tbody>
</table>

* Based on a crop of 180 days and a sugar price of USD500 /t

The gyratory reciprocating motion screener shown in Figure 1 is commonly used in the USA sugar industry, and in Mexico they are used in 25 sugar mills and in eight factories in Colombia and three factories in Peru.

Fig. 1—Gyratory reciprocating motion screener.

**Screening to separate overs and fines**

Table 3 shows the data of the screening of the sugar from two sugar mills that produce refined sugar using a gyratory reciprocating screener. The data represent the percentage of sugar in each size fraction. The efficiency of the screener allows the mills to output sugar containing overs and fines of about 2% only.

<table>
<thead>
<tr>
<th>Screen size range (Mesh #)</th>
<th>Ingenio El Potrero</th>
<th>Ingenio Tres Valles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-screened sugar (%)</td>
<td>Screened sugar (%)</td>
</tr>
<tr>
<td>+20</td>
<td>5.97</td>
<td>0.5</td>
</tr>
<tr>
<td>–20 / +70 mesh</td>
<td>87.79</td>
<td>97.50</td>
</tr>
<tr>
<td>–100</td>
<td>6.24</td>
<td>2</td>
</tr>
</tbody>
</table>
In both cases the final product is ready to:

- Fulfil the requirements of the companies that produce mixtures with flour of similar size for making bread, cereals, cookies and need sugar with a little overs and fines.
- Supply this sugar to any market with little risk of lumping during storage and transportation.

Ingenio Tres Valles did not receive any claim for lumps during the last campaign, because the sugar met every test with temperature between 32 and 35°C and with a very low content of fines. In the 2007–2008 crop a plate cooler was used without a screen and they received few claims (Urrutia et al., 2008), and finally in the last crop the product was sent to many places through an agreement with Cargill.

Reichling (2008) established that, when sugar with low fines content is packaged at temperatures near the storage environment, no lumping will occur during storage and transportation.

The results in the elimination of overs shown in Table 1 indicate that the machine with the gyratory motion at the feed end and straight-line motion at the discharge end is more efficient at maximising the compliance level than the other screener tested. Since these results were obtained in the easier application, it did not justify making a test using the other screeners for the more difficult and expensive application to eliminate both the overs and fines.

**Handling the overs of the sugar**

Taking into account that by using a high efficiency screener, the separation of the overs without any on-spec sugar is guaranteed, then options to handle the overs can be evaluated. Normally almost all the sugar mills dissolve the overs obtained by screening of the product. It is common in the industry to dissolve the overs in several places of the factory depending on whether it is refined or plantation sugar being produced and the criteria of management. The effective sugar loss depends on where in the process the sugar is dissolved and can be between 10–20%. A 10% loss is a reasonable assumption for this discussion.

In any calculation, a loss of 10% of overs is an area of opportunity since this represents about 1% of the sugar and the loss of 0.1% of the sugar produced.

A second option is to mill the overs to produce a sugar with a similar size to the product sugar. A pin mill made in mild steel and equipped with a 11 kW motor was investigated for this option (see Figure 2).

![Fig. 2—Pin Mill model Simpactor 3B with 11 kW motor.](image-url)
**Refined sugar**

A sample of overs separated in a high efficiency screener was obtained from Ingenio Tres Valles and processed through the milling machine. The sieve data for both the sample of overs collected and the sample after milling are given in Table 4. The milled material had a very good particle size distribution with 66.7% in the size fractions between –16 mesh and +80 mesh.

<table>
<thead>
<tr>
<th>Mesh size</th>
<th>Sugar in each size fraction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overs</td>
</tr>
<tr>
<td>+ 6 (3.35 mm)</td>
<td>36.5</td>
</tr>
<tr>
<td>–6 / + 16 (1.18 mm)</td>
<td>63.5</td>
</tr>
<tr>
<td>–16 / +25 (0.71 mm)</td>
<td>13.8</td>
</tr>
<tr>
<td>–25 / +35 (0.5 mm)</td>
<td>11.9</td>
</tr>
<tr>
<td>–35 / +60 (0.25 mm)</td>
<td>32.3</td>
</tr>
<tr>
<td>–60 / +80 (0.18 mm)</td>
<td>8.7</td>
</tr>
<tr>
<td>–80</td>
<td>3.9</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
</tr>
</tbody>
</table>

**Plantation sugar**

When the oversized plantation sugar was milled, the results in Table 5 indicate that only 16% of the original sample remained outside the acceptable size range.

<table>
<thead>
<tr>
<th>Mesh size</th>
<th>Sugar in each size fraction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overs</td>
</tr>
<tr>
<td>+ 6 (3.35 mm)</td>
<td>79</td>
</tr>
<tr>
<td>–6 / + 10 (2 mm)</td>
<td>21</td>
</tr>
<tr>
<td>–10 / +25 (0.71 mm)</td>
<td>77.8</td>
</tr>
<tr>
<td>–25 / +35 (0.5 mm)</td>
<td>3.0</td>
</tr>
<tr>
<td>–35 / +60 (0.25 mm)</td>
<td>2.5</td>
</tr>
<tr>
<td>–60 / +70 (0.212 mm)</td>
<td>0.7</td>
</tr>
<tr>
<td>–70</td>
<td>2.9</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
</tr>
</tbody>
</table>

**Handling the milled sugar**

In view of the results obtained through milling, it is worthwhile considering options to use the milled sugar. These options include:

1. Given that the overs are only 1% of the total sugar produced the best way to handle the milled sugar is to mix all the milled sugar with the screened on-spec sugar. The new overs and fines represent only a very small proportion of the total product.
2. The milled sugar could be sent to the inlet of the screener and, in this way, remaining overs will be separated and the milled sugar and the fines will pass with the on-spec sugar.
3. Send the milled sugar to a separate bin based on its quality. The technologist can mix the sugar according to the product specification required at the time.
Table 6 shows the increase in colour when 1% of milled sugar is mixed with 99% of on-spec sugar. The increase is within the error range of the method.

However, there are at least another two ways to utilise this material to allow the sugar technologist to select the most appropriate choice according to the particular conditions.

<table>
<thead>
<tr>
<th>Sugar type</th>
<th>Colour standard</th>
<th>Nominal values</th>
<th>Milled overs</th>
<th>Colour increase in the mix 1/99 (IU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refined</td>
<td>35</td>
<td>22</td>
<td>135</td>
<td>+1.13</td>
</tr>
<tr>
<td>Plantation</td>
<td>600</td>
<td>500</td>
<td>1335</td>
<td>+8.35</td>
</tr>
</tbody>
</table>

In an exercise to examine financial implications of milling the overs fraction, the only consideration was the loss related to the dissolution of the sugar and not other costs such as water consumption or additional energy used.

The investment recovery time of this project is very fast as is seen in Table 7. In the worst case for a sugar mill that produces about 20 t/h, less than one crop is needed to pay for the machine, using a very conservative estimate of the loss of sugar by dissolution.

This is a real opportunity area to improve the efficiency in the packaging area with only a minimal investment.

<table>
<thead>
<tr>
<th>Capacity, (t/h)</th>
<th>Overs dissolved, (t/h)</th>
<th>Loss of sugar by dissolution, (USD/week)</th>
<th>Investment recovery time (weeks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.2</td>
<td>1680</td>
<td>18</td>
</tr>
<tr>
<td>50</td>
<td>0.5</td>
<td>4200</td>
<td>7.2</td>
</tr>
<tr>
<td>100</td>
<td>1.0</td>
<td>8400</td>
<td>3.6</td>
</tr>
</tbody>
</table>

Note: 1% of overs in the sugar, 10% loss of sucrose by dissolution, price of sugar is USD500/t, and price of the mill is USD30 000 FOB for a sugar mill in the zone of Cordova, Veracruz, Mexico.

Sugar conveying

For this test, three types of conveyors (screw, belt and vibratory) of a similar 10 m length were tested. Since this is the final step in the product handling system, careful handling is required.

With belt conveyors it is possible to lose a substantial portion of the sugar to the floor. Tests showed losses of up to 1 t per 8 h in sugar mills producing 1000 t/day of sugar.

This loss represents 0.3% of production. In other mills, losses of up to 0.6% were measured.

Closed conveyors like screw or vibratory conveyors do not experience this magnitude of loss. A saving of up to 500 kg for each 1000 t of sugar is possible and represents USD45 000 in one crop.

In looking at the problem, an exercise was undertaken under the assumption that only 0.1% of sugar is lost using belt conveyors.

Table 8 shows that if vibratory conveyors are used to replace belt conveyors, the investment is recovered in less than one crop, and in the future years no financial losses will be realised.
Table 8—The cost of 0.1% losses using belt conveyors.

<table>
<thead>
<tr>
<th>Capacity, (t/h)</th>
<th>Tonnes lost per hour</th>
<th>Tonnes lost in a crop</th>
<th>Monetary loss (USD)</th>
<th>Cost of a vibratory conveyor for same job (USD)</th>
<th>Investment recovery time (crop)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.02</td>
<td>86.4</td>
<td>43 200</td>
<td>40–50 000</td>
<td>1–1.25</td>
</tr>
<tr>
<td>50</td>
<td>0.05</td>
<td>216</td>
<td>108 000</td>
<td>55–70 000</td>
<td>0.5–0.65</td>
</tr>
<tr>
<td>100</td>
<td>0.1</td>
<td>432</td>
<td>216 000</td>
<td>80–100 000</td>
<td>0.37–0.46</td>
</tr>
</tbody>
</table>

Screw and vibratory conveyors

Screw and vibratory conveyors are closed conveyors that usually do not create any loss by spillage. An example of a vibratory conveyor is shown in Figure 3.

Fig. 3—Example of a vibratory conveyor.

Tests were conducted on two screw conveyors and two vibratory conveyors to assess whether either type of conveyor could cause crystal damage and increase the fines content in the sugar. The results in Figure 4 show that both screw conveyors that were tested caused crystal damage while the vibratory conveyors caused no damage.

Fig. 4—Creation of fines during sugar conveying in screw and vibratory conveyors.
In this case the disadvantage is not related with a loss of sugar, but the lower quality sugar through the particle size characteristics of the product because the sugar conveyed by screw has an increased quantity of fines.

Conclusions

There are new opportunities for improving the efficiency in the packaging area that include:

- Using gyratory reciprocating screeners, 70 t of on-spec sugar can be recovered if a vibratory screener is used or 100 t of sugar if a fixed screen is replaced. The cost of the investment would be recovered in less than one crop.
- Compliant sugar with good grain size and low fines becomes available to send to any place without the risk of lumping when high efficiency screeners are used to eliminate overs and fines.
- The milling of overs instead of dissolution is a project with a fast recovery time. In the worst case for a sugar mill that produces about 20 t/h, the recovery time is less than 18 weeks. This is a real opportunity area to improve the efficiency in the packaging area with only a small investment.
- Using vibratory conveyors, it is possible to eliminate losses of 0.1% that represent a loss of 80–400 t of sugar per crop compared with belt conveyors because the vibratory conveyor does not produce fines during the conveying of sugar. If existing screw conveyors that can generate up to 3% fines are replaced, then the benefit is much more significant.

REFERENCES


NUEVAS IDEAS PARA EL MEJORAMIENTO DE LA EFICIENCIA EN EL ÁREA DE EMPAQUE.

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PALABRAS CLAVE: Área de Empaque, Tamizado de Azúcar, Molienda de Retenidos, Transporte de Azúcar.

Resumen
En la búsqueda de mejores eficiencias en el área de empaque, donde se maneja el producto final, se estudió el desempeño de diferentes equipos de tamizado, de transporte de producto final y de molienda de los materiales retenidos en los tamices. Para el estudio de estas operaciones unitarias, se reunió información de varios ingenios y se compararon diferentes alternativas para tamizado de azúcar. La mayor eficiencia se obtuvo con el uso de un tamiz giratorio y reciprocatante, eliminando entre 1 y 3% de las pérdidas de azúcar dentro de especificaciones comparado con el desempeño de otras tecnologías para esta operación. Se estudió la posibilidad de moler el material retenido en el proceso de tamizado y se comparó con la disolución tradicional de este material. Se efectuó una prueba de molienda con azúcar blanco y refinado y se recuperó un 10–20% del azúcar que normalmente se disuelve y va a las mieles. Finalmente, se discuten algunos de los resultados obtenidos en el transporte de azúcar usando conductores vibratorios en lugar de transportadores de tornillo. Se encontró que se recuperó entre 0,5–3,0% del azúcar cuando se usaron conductores vibratorios en lugar de conductores de banda. En el caso de los transportadores de tornillo, se encontró una degradación de tamaño de cristal del orden de 1–3%. Se concluye que hay una oportunidad de recuperar más azúcar en esta área usando tecnología más eficiente.
ON-LINE MONITORING OF FACTORY PROCESSES

By

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Abstract

THE KNOWLEDGE of mass and energy flows in a cane sugar factory is a crucial aspect in order to enhance the plant performance and detect process deficiencies. The development of the Advanced Monitoring System (AMS) based on the Sugars software allows nowadays visualising the sugar process by connecting the software to the process and laboratory information system. The AMS was first introduced in 2004 to the sugar industry. Experience gained over the last few years is reported in this paper. Besides the creation of the mass and energy balance, the system can be used for data reconciliation with special regard to measured flows, temperatures and pressures as well as laboratory analytical data. Calculated and measured data are compared to facilitate improvements to process performance and reliability. The AMS requires approximately 100–150 data points (cane mass flow, analytical data, pressures and temperatures) to characterise and display the actual process operations with high accuracy. The AMS is a process monitoring tool allowing the sugar engineer to validate the operation and performance of the process. By defining benchmark values (key performance indices), it is possible to monitor and subsequently improve the performance of process equipment and the processes.

Introduction

The Advanced Monitoring System (AMS) is a software package which was specifically developed for the sugar industry (Morgenroth and Pfau, 2004). The AMS package consists of the Microsoft® Visio® program and the Sugars™ program combined with a data exchange add-on that allows the importing and exporting of various types of process information.

Microsoft Visio is used for the graphical and operating data display of the sugar processing stations, for example, extraction, purification, evaporation and crystallisation.

The Microsoft Visio program is linked with the Sugars program to calculate mass flows, temperatures, purities, etc. Approximately 100–150 data points from the laboratory and process control system (e.g. dry substances, purities, temperatures, pressures and flows) are imported via an Extensible Markup Language (XML) file.

The XML file is created on demand by the Management Execution System (MES) of the factory and subsequently imported to the AMS. Following the import of data, the AMS calculates a closed mass and energy balance of the factory.

It is possible to do balances for daily, weekly or monthly production overviews. The AMS helps process engineers and operators to analyse the operation and performance of each processing station as well as the entire factory.
Applicability

The AMS is flexible regarding the type of factory to be analysed because it uses individual station modules that can be arranged to suit the process being simulated. Typical applications are cane sugar factories, beet sugar factories and sugar refineries. The distillery process can also be displayed with regard to simulated mass balances. Some parameters that are usually fixed (like heating surface areas) can either be integrated as constants into the model, or imported in accordance with the requirements. For example, the area of active heating surface could be imported.

Figure 1 shows an open model property window for a heat exchanger. The outlet temperature and the operating heating surface are imported into the model by the AMS from the MES database. As a result, the calculated heat transfer coefficient (k-value) is shown in correlation to the optimum k-value.

Fig. 1—Heat exchanger with open model property window.

Description of on-line monitoring performance steps

Approximately 100–150 measured analytical, temperature, pressure and flow data values from the sugar process of the factory are required in order to perform a consistently balanced model of the complete sugar manufacturing process. It is important that the quality of imported or measured process variables and analytical data is high, meaning sensors need to be checked regularly for accuracy and process samples need to be treated in accordance with modern laboratory routines and analytical methods. In some countries, gravimetric brix measurements are still common and they cannot be used as a basis for the mass and energy balances. In such cases, the laboratory needs to switch to internationally recognised analytical methods.

A MES integrating the process control and the laboratory system provides the basis for data handling and transfer. The appropriate monitoring intervals need to be determined and this aspect is managed in the MES as the availability of different data types can vary. While process variables such as flows, pressures and temperatures are usually available instantly, averaged values can be easily created.

Analytical data are more difficult to collect as this information is usually not provided online, but instead by the laboratory once each analysis has been completed. The measurement intervals depend on the importance of the measured values for general factory control as well as the available man power and laboratory policy. Time intervals for analytical data usually vary between two hours and one week.
The task of the MES is to gather all the required data on demand for a selected time frame. The MES creates an XML data file that is subsequently imported to the AMS and processed in order to calculate a mass and energy balance. In the case where no analytical data have been measured within the selected time frame, it is necessary to decide if typical values will be used for the calculations or if the last available data should be used. The last available data are usually used in such cases.

To achieve a highly accurate mass and energy balance of the sugar process, a relatively constant operation of the factory is required. This is usually not a problem in modern beet sugar factories or refineries, but stoppages are much more common in cane sugar factories. Therefore, it is required to choose a time interval that is long enough to gather adequate data, but short enough to exclude longer stops or low capacity periods. Short stops of less than 20 minutes and flow fluctuations do not impact on the mass and energy balances if calculated averages of process variables are used to smooth out short term variations.

Typically once a day, fresh data from the previous day are imported and then used for the process display and analysis.

Other data like heating surfaces can be fixed in the model but also can be imported to reflect actual heating surfaces in use for cases where individual heaters or evaporators are taken off-line for cleaning or complete evaporation trains are stopped, e.g. for cleaning.

Other available process data (especially flows) not required for the mass and energy balance itself can be imported to verify the calculated data. For example, usually only the cane processing rate is imported as a mass flow measured by a weighing scale to the program. All other flows are calculated in order not to rely on data such as volumetric flow measurements. The AMS helps to compare calculated and measured data and allows data reconciliation. Experiences have shown that often more than 50% of the process flow measurements as well as many temperature and pressure sensors are in error. The reasons for these errors are typically scaling on probes and instrument sensors and incorrect installation of instruments. By comparing the AMS results with process data from instruments and sensors, significant variations can trigger the need for recalibration.

The AMS model also can be used to examine different operating scenarios and the impact of these changes to the process. For example, the impact of using different process values on the steam demand can be easily examined by shifting the vapour extraction to a different effect. Also, a colour balance can be performed by the program. This feature can be used to predict the final sugar colour or it can be used to model different operating scenarios.

The detailed view of the process and its performance allows quick detection of weak points like underperforming equipment or process units as well as inaccurate process values. This allows correction or adjustments to the operation of the process to achieve improved processing results. By on-line access of the XML data exchange file, the monitoring of processes can be done over the internet at any time.

Examples

The following examples are provided to give an understanding of how the AMS works. Selected examples are displayed here for processing stations (and single processes). Table 1 details the legend for the subsequently displayed figures. Figure 2 shows a five effect evaporation station operating with falling film plate evaporators in a cane sugar factory. Similar evaporation set ups are already employed in a couple of cane sugar factories. Clarified juice enters the 1st effect with a brix of 13.6 and a temperature of 116°C and leaves the evaporation station with a brix of 65 and 97.2°C.

The properties of the clarified juice including purity, brix and mass flow (black values) are calculated by the simulation model. The violet values show the measured values imported from the laboratory and process for comparison purposes.
It is possible to compare the measured values (temperatures, brix, mass flows) with the calculated values (black). Normally the difference between the calculated and measured values should not be more than 1–3%. This comparison enables the process or instrument engineer to check for defective flow meters or temperature transmitters. The green values are imported values from the process and the laboratory.

In the example shown in Figure 2, the vapour pressures and operating heating surfaces for each effect and the syrup brix are necessary to do the mass and energy balance and display selected values of the evaporation station. As a further feature of the AMS, key performance indices (KPI) are shown (brown values). For the evaporation station, effective temperature differences and k-values for each effect are calculated. These KPIs enable the process engineer to check the performance of the evaporators and to determine the amount or severity of fouling. The actual k-values calculated from the measured process variables can be compared with theoretical benchmark values and the resulting actual/optimum ratio is displayed (as a percentage). This KPI can be used to trigger the cleaning process.

Figure 3 shows the performance of an A centrifugal station in a cane sugar factory. The input values for purity, temperature and mass flow of A massecuite to the centrifugals are calculated by the AMS (black values). Analytical data including purities and dry substances for the A Molasses and A Sugar are imported to the simulation model (green values) from the MES. The
A simulation model calculates the flows for A Sugar, A Molasses and the wash water amount to the centrifugals. These calculated values can be compared with measured values (violet) from the process and differences like the wash water amount in the example can be detected. The wash water amount to the centrifugals (5.8% on massecuite) and the crystal losses (20.0%) are calculated to provide KPIs and give the process engineer in the factory the ability to easily and quickly check the performance of installed equipment. Large crystal losses without an increase in wash water can indicate the need to change the centrifugal screens.

**Fig. 3—Simulation of an A centrifugal station.**

Figure 4 shows the power station of a cane sugar factory.

**Fig. 4—Power station simulation.**
In Figure 4, two 9 MW backpressure turbo generators and a 92 bar (abs), 520°C, 100 t/h boiler are shown. Only seven import values are necessary to simulate this power station (green values). The simulation provides data on the mass flows and properties of live steam from the boiler, exhaust steam to process, steam to turbo generators or feed water amount.

The KPIs for this example are shown for the specific steam consumption and the different isentropic efficiencies of the turbo generators. Figure 4 shows turbo generator 1 is operating at a lower performance compared to turbo generator 2 (based on isentropic efficiency) because it is running only partially loaded. Also, while not displayed, the live steam demand on cane could be easily calculated as an additional KPI.

In the case where a distillery is attached to the factory, the mass balance of the distillery process can be simulated and displayed (Figure 5) to show the amount of ethanol produced in addition to mass balances of sugar and power for the entire factory.

**Conclusions**

The installation of AMS in a cane or beet sugar factory or in a sugar refinery offers the possibility to monitor processes closely and provide instant performance data on demand. It is possible to obtain a lot of KPIs for different equipment like centrifugals, heat exchangers, evaporators, turbo generators, etc. The operators or the process engineers are able to visualise the real process in the adapted simulation model for daily, weekly or monthly imported data. The AMS has been operating since 2005 in three cane sugar factories in Brazil and assists the management in analysing and optimising the performance and operation of processing stations and the entire factory.

**Acknowledgements**

The authors would like to thank the management and employees of the Zilor company, Brazil for entrusting the installation of the AMS in their factories and the excellent partnership that was the basis for the successful application of the system.

**REFERENCE**

SURVEILLANCE EN LIGNE
DES PROCESSUS D'USINE

Par

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MOTS-CLEFS: AMS, Bilans de Masse et d'Energie, Surveillance en Ligne,
Indice ee Performance, Modèle ee Simulation.

Résumé

LA CONNAISSANCE des débits de masse et de l'énergie dans une usine à sucre est un aspect crucial afin d'améliorer les performances et de détecter les anomalies du processus. Le développement de l'Advanced Monitoring System (AMS) basé sur le logiciel Sugars permet la visualisation du processus, en connectant les systèmes d'information du processus et du laboratoire. L'AMS a été introduit en 2004 dans l'industrie sucrière. L'expérience acquise au cours des quelques dernières années est décrite dans ce document. Le système permet la création de bilans massique et énergétique et peut être utilisé pour le rapprochement de données basées sur des débits mesurées, des températures et des pressions ainsi que les données d'analyse de laboratoire. Les données calculées et mesurées sont comparées pour faciliter les améliorations des performances et la fiabilité. L'AMS nécessite environ 100–150 points de données (débit massique de canne à sucre, données analytiques, pressions et températures) pour caractériser et afficher les opérations de processus réel avec une grande précision. L'AMS est un outil permettant à l'ingénieur de valider le fonctionnement et les performances du processus. En définissant les valeurs de référence (indices de performance clés), il est possible de surveiller et d'améliorer les performances des équipements et des processus.
MONITOREO EN LÍNEA
DE PROCESOS FABRILES

Por

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PALABRAS CLAVE: AMS, Balances de Masa y Energía, Monitoreo en Línea, Indicadores Clave de Desempeño, Modelos de Simulación.

Resumen
El conocimiento de los flujos de masa y energía en un ingenio es crucial para mejorar el desempeño y detectar deficiencias de proceso. El desarrollo del Advanced Monitoring System (AMS), basado en el programa Sugars, permite actualmente la visualización de los procesos por medio de la conexión del software al sistema de información de proceso y laboratorio. El AMS se introdujo en el 2004 a la industria azucarera. En este trabajo se reporta la experiencia ganada durante este corto período. Además de la creación del balance de masa y energía, el sistema puede ser usado para reconciliación de datos, con especial interés en las mediciones de flujos, temperaturas y presiones así como en los datos analíticos de laboratorio. Se comparan los datos calculados y los medidos para facilitar mejoramientos al desempeño de los procesos y a la confiabilidad. El AMS requiere aproximadamente 100–150 datos (flujo de caña, datos analíticos, presiones y temperatura) para caracterizar y presentar las operaciones reales de proceso con alta precisión. El AMS es una herramienta de monitoreo que permite al ingeniero validar la operación y desempeño del proceso. Con la definición de valores de benchmarking (indicadores clave de desempeño) es posible monitorear y mejorar en consecuencia el comportamiento del equipo y los procesos.
IMPLEMENTATION OF ON-LINE NEAR INFRARED (NIR) TECHNOLOGIES FOR THE ANALYSIS OF CANE, BAGASSE AND RAW SUGAR IN SUGAR FACTORIES TO IMPROVE PERFORMANCE

By

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KEYWORDS: Near Infra-Red Spectroscopy, Online Analysis, Bagasse Analysis, Sugar Analysis, Process Control.

Abstract

BSES LIMITED has a long history of developing and commercialising NIR technology for sugar industry applications spanning plant breeding, laboratory and online sugar factory use. This paper traces the development of online NIR systems with FOSS Pacific, for the real-time analysis of cane, bagasse and sugar, describing a range of applications currently applied within sugar factories. The Cane Analysis System (CAS) was developed primarily to measure real-time fibre content of a cane consignment for payment purposes. This enables payment on the overall quality of a consignment rather than making assumptions from average figures. CAS uses a FOSS Direct Light 5000 instrument, with ancillary systems developed for sample presentation, data analysis and integration with mill control systems. Further CAS applications for ash, dry matter, pol and brix in both cane and juice, as well as commercial cane sugar (CCS), were subsequently developed. Data from these calibrations have successfully been used to audit mill laboratories, derive cane quality indices, implement automated control strategies, develop alternative payment systems and provide data on individual farms/blocks, enabling targeted solutions for areas with productivity issues. Based on this platform, online bagasse (BAS) and sugar analysis systems (SAS) were developed. BAS measurements can provide quality-based assessments of bagasse suitable for feed-forward to boiler stations. When linked with a CAS on the same milling train, the effects of mill settings, maceration control and cane quality on pol extraction are determined in real-time, enabling the development of strategies to maximise extraction. SAS calibrations are used to monitor and control critical processes in the production of LoGIcane™, the world’s first low glycemic index sugar which was commercialised and released in Australian in 2009. The development of online NIR measurement systems for sugar factories has seen quality, payment and control strategies established, which are not possible using normal laboratory data. Almost 30 systems have been installed worldwide, and further uses for online NIR data continue to be developed by existing users in conjunction with BSES and FOSS.

Introduction

In recent times, near-infrared (NIR) spectroscopic instrumentation has been developed for the rapid and reliable analytical determination of parameters of interest within petrochemical (Larrechi and Callao, 2003), beverage (Rodriguez-Saona et al., 2001), food (Dodds and Heath, 2001) and pharmaceutical industries (Carlsson and Janne, 1995). Routine NIR analyses have significant advantages over traditional wet chemistry techniques, particularly in terms of labour and consumable costs, throughput, non-destructive sample preparation and analysis, potential generation of real time on-line results and reduced risk where hazardous materials or procedures are involved.
These advantages refer specifically to the analysis itself, whereas further benefits can be obtained from applying the real time data obtained for process control, payment systems and the prediction of multiple constituents from single spectral measurements.

With respect to sugar industry applications, there are well-documented descriptions of at-line NIR spectroscopic techniques used for plant-breeding purposes (Berding et al., 1989; Brotherton and Berding, 1995, 1998). These analyses were primarily performed on shredded or fibrated cane, and were followed by further reports providing data on other substrates derived from sugarcane and various factory streams including molasses and mixed juice (Brotherton and Berding, 1995; Schäffler et al., 1993; Simpson and Oxley, 2008).

The successful plant breeding applications led to an expansion of research activities at BSES Limited, culminating in the development of on-line NIR systems for sugar mill applications. These applications have been developed in conjunction with FOSS as providers of NIR hardware, and have been commercially released as the Cane Analysis System (CAS) and the Sugar Analysis System (SAS). An analogous Bagasse Analysis System (BAS) is currently undergoing development prior to commercial release, although two prototype systems are operational at Mulgrave Central Mill (Cairns, Australia) and the Costa Pinto Mill (Brazil). This paper describes past and recent applications derived from these on-line NIR measurement systems.

Materials and methods

Experimental

Chemicals: Folin-Ciocalteu reagent and (+)-catechin standard were purchased from Sigma-Aldrich (St Louis, MO) with sodium carbonate obtained from Labserv (Melbourne, Australia). All chemicals used were analytical grade.

Polyphenol Analysis: 40 g of raw sugar sample was accurately weighed into a 100 mL volumetric flask. Approximately 40 mL of distilled water was added and the flask agitated until the sugar was fully dissolved after which the solution was made up to final volume with distilled water. The polyphenol analysis was based on the Folin-Ciocalteu method (Singleton and Rossi, 1965) using a protocol adapted from the work of Kim et al. (2003). In brief, a 50 µL aliquot of appropriately diluted raw sugar solution was added to a test tube followed by 650 µL of distilled water. A 50 µL aliquot of Folin-Ciocalteu reagent was added to the mixture and shaken. After 5 minutes, 500 µL of 7% Na₂CO₃ solution was added with mixing. The absorbance at 750 nm was recorded after 90 minutes at room temperature. A standard curve was constructed using standard solutions of catechin (0–250 mg/L). Sample results were expressed as milligrams of catechin equivalent (CE) per 100 g raw sugar.

Analytical results for pol, brix, ash, fibre, moisture were generated using standard methods within the Australian sugar industry (BSES, 1991). Bagasse samples were analysed for lignin content according to the methods published by the US National Renewable Energy Laboratory (2008).

System description

On-line NIR systems were developed based on the NIRSSystems 5000 scanning monochromators with direct light attachment and the InfraSoft International (ISI) chemometrics package. The attached scanning head is sealed against the mill chute for both CAS and BAS installations while, for the SAS configuration, it is mounted above the conveyor belt which transports raw sugar from the dryer. For all configurations, the substrate is scanned through a heat-treated toughened glass window mounted within a stainless steel housing. Vibration dampening systems are installed within both the scanning head unit and the NIR instrument cabinet, which is also fitted with an air-conditioning system and an uninterruptible power supply. The system is integrated with the mill payment and control computers, and software was developed to process relevant mill signals, control scanning equipment and to distribute data to the appropriate mill.
systems. This software also interfaces with mill tracking systems to ensure that individual consignments of cane are recognised, and is capable of registering various errors, alarms and internal checks to provide result integrity.

An important feature of these systems is their setup within a secure networked environment. In this way, online diagnostics, system checks, uploading of new and/or upgraded calibration equations and data storage can be handled by remote operators either over a local/wide area network or via the internet. Methods developed for sampling, analysis, NIR scanning, equation development, equation validation and the evaluation of system performance have been described previously (Staunton et al., 1999).

Cane Analysis System (CAS)

The CAS system has been well described previously and many applications of CAS data have been reported. It was originally envisaged primarily as a means of determining the fibre content of individual consignments of cane supplied to the mill, thereby providing a way of moving away from class fibre systems or payment methods in which cane fibre values were averaged or given assumed values. Upon the development of the system, it became rapidly apparent that the ability to provide real time data provided strong incentives to examine additional options, develop useful calibrations and apply them to gain direct benefit in both the mill and the field.

In particular, CAS data have been used to develop online cane analysis systems for fibre analyses (Staunton et al., 1999), payment purposes (Staunton et al., 2004), cane-quality schemes (Pope et al., 2004), and for process control purposes using fibre rate control (Jones et al., 2002). There are currently 23 CAS installations worldwide supporting these applications within sugar mills.

Sugar Analysis System (SAS)

An earlier report outlined the initial development of the SAS system (Bevin et al., 2002), where an instrument configuration similar to that developed for CAS was used to measure various sugar parameters within sugar mills and at bulk sugar terminals. This report also outlined control charting techniques and comparisons of NIR versus laboratory analyses. For mill applications, the SAS sampling head is mounted over a sugar conveyor belt (Figure 1). The plough shown on the right hand side of the setup has been designed to maintain a particular depth of sugar on the belt as it passes under the scanner from right to left, thereby minimising data scatter and error. A description follows of the development of specific SAS equations for process control and quality monitoring of a low glycemic index (GI) sugar product produced at Mossman Central Mill during the 2008 crushing season.

![Fig. 1—Typical mounting system for the SAS scanning head over a sugar conveyor belt.](image-url)
LoGiCane™ is the world’s first all natural low GI cane sugar product and was developed in Australia by Horizon Science. It was produced on a large scale for the first time during the 2008 season at Mossman Central Mill and was officially launched in March 2009 (Burke, 2009). LoGiCane™ has been independently tested and certified by the Glycemic Index Foundation in Australia with a low GI of 50, whereas white sugar has a medium to high GI of 65.

Low GI foods provide a health benefit by producing gradual increases in blood glucose and insulin levels following consumption, thereby having implications for weight control and diet choice for people with type 1 and type 2 diabetes.

The GI of LoGiCane™ is reduced due to the presence of various natural components of sugarcane, particularly polyphenols and minerals, which have been added back during the production process.

Assays for these components are vital to characterise polyphenol and mineral levels across the production process and within the final product. In conjunction with Horizon Science and Mossman Central Mill, BSES developed an online process control solution for LoGiCane™ production using SAS technology.

The SAS instrument installed not only measures traditional sugar parameters such as pol, moisture, ash, colour and reducing sugars, but also provides data on the concentrations of polyphenols, minerals and a measure of antioxidant capacity.

These critical measurements provide instant process feedback, enabling the development of process control solutions based on the SAS data, as well as systems to ensure product consistency.

Calibration and validation plots for the prediction of total phenolics in sugar are shown in Figures 2 and 3. The calibration results were very good and included spectral results from two separate laboratory instruments.

When applied to the SAS instrument, the validation results contained some bias, scatter and skew; however, the results proved to be adequate for process control and would improve with further development. Importantly, the calibration developed contains no data from the online SAS instrument.

The validation results are demonstrating effective calibration transfer even at this early stage of development. As this development process continues (viz. inclusion of on-line SAS data and instrument variation in the global calibration), significant improvements in equation performance are expected.

\[
y = 0.9443x + 2.2735 \\
R^2 = 0.9474 \\
SEC = 5.81 \\
Bias = -0.09 \\
N = 162
\]

Fig. 2—Calibration plot for total phenolics in sugar at Mossman Central Mill. Phenolic units are mg catechin equivalents per 100 g sugar.
Bagasse Analysis System (BAS)

The development of BAS instrumentation has been described previously (Staunton and Wardrop, 2006) and the system will be available commercially in the near future. The previous report described in some detail the system development, sampling, analysis and preliminary factory applications for calorific value estimation of bagasse to aid boiler operation as well as the determination of online pol extraction across the milling train where both CAS and BAS installations are present. Here data are presented for online pol extraction from the 2008 crushing season obtained from the two prototype BAS installations at Mulgrave Central Mill (Australia) and Costa Pinto Mill (Brazil), where both milling trains also have CAS installations at the front end. Early developmental work on an online lignin determination on bagasse is also presented.

Online pol extraction

The Mulgrave Central Mill BAS installation is currently in its fifth year of continuous operation, having been installed during the 2005 season. In order to develop a measure for online pol extraction, appropriate calibration equations and software were developed to calculate pol extraction using real time data from the mill tracking systems and the CAS and BAS units and applying the following formula which assumes no loss in fibre (Staunton and Wardrop, 2006).

\[
Polextraction = 100 \times \left(1 - \frac{Pol_b \times Fibre_c}{Fibre_b \times Pol_c}\right)
\]

where: \(c = \text{cane, } b = \text{bagasse.}\)

The 2008 crushing season laboratory validation statistics for a selection of CAS and BAS calibrations are shown in Table 1. The low levels of bias observed and the fact that standard errors of prediction (SEP) are lower than the equation error control limits (ECL) show that the CAS calibrations performed close to or within expectations in terms of analysis accuracy and precision. The BAS validation statistics show relatively poor slope and coefficients of determination due to the relatively high SEPs, combined with restricted ranges in parameter values. This is especially true for pol%bagasse and is due, in part, to the difficulties involved in collecting representative samples of bagasse that span a sufficient range of pol%bagasse values.
Table 1—Calibration equations and validation statistics for Mulgrave Central Mill CAS and BAS installations.

<table>
<thead>
<tr>
<th>CAS parameter</th>
<th>SEP</th>
<th>Error control limit</th>
<th>Slope</th>
<th>Bias</th>
<th>$R^2$</th>
<th>Range</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pol%juice</td>
<td>0.32</td>
<td>0.38</td>
<td>0.94</td>
<td>0.017</td>
<td>0.97</td>
<td>11.9–23.9</td>
<td>11312</td>
</tr>
<tr>
<td>Brix%juice</td>
<td>0.30</td>
<td>0.38</td>
<td>0.93</td>
<td>0.009</td>
<td>0.97</td>
<td>15.2–26.2</td>
<td>11312</td>
</tr>
<tr>
<td>Direct CCS</td>
<td>0.32</td>
<td>0.32</td>
<td>0.95</td>
<td>0.018</td>
<td>0.95</td>
<td>8.0–18.0</td>
<td>11312</td>
</tr>
<tr>
<td>Fibre%cane</td>
<td>0.69</td>
<td>0.66</td>
<td>0.73</td>
<td>–0.12</td>
<td>0.80</td>
<td>11.4–22.4</td>
<td>588</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BAS parameter</th>
<th>SEP</th>
<th>Error control limit</th>
<th>Slope</th>
<th>Bias</th>
<th>$R^2$</th>
<th>Range</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter%bagasse</td>
<td>1.04</td>
<td>1.07</td>
<td>0.64</td>
<td>0.04</td>
<td>0.64</td>
<td>47.5–56.2</td>
<td>160</td>
</tr>
<tr>
<td>Moisture%bagasse</td>
<td>1.04</td>
<td>1.07</td>
<td>0.64</td>
<td>–0.04</td>
<td>0.64</td>
<td>43.8–52.5</td>
<td>160</td>
</tr>
<tr>
<td>Fibre%bagasse</td>
<td>1.19</td>
<td>1.13</td>
<td>0.6</td>
<td>–0.11</td>
<td>0.61</td>
<td>43.2–54.1</td>
<td>160</td>
</tr>
<tr>
<td>Ash%bagasse</td>
<td>1.09</td>
<td>1.48</td>
<td>1.00</td>
<td>–0.04</td>
<td>0.65</td>
<td>0.8–9.0</td>
<td>160</td>
</tr>
<tr>
<td>Pol%bagasse</td>
<td>0.24</td>
<td>0.22</td>
<td>0.28</td>
<td>–0.02</td>
<td>0.31</td>
<td>0.7–2.0</td>
<td>160</td>
</tr>
</tbody>
</table>

The pol extraction validation results are shown in Figure 4. Both the slope and the correlation coefficient for the linear regression were considered to have utility, especially when considering the relatively small population size, the narrow range of values for the extraction data and the relatively high standard errors of prediction reported for BAS constituents.

Even with these limitations, online pol extraction by NIR represents a significant advance in the monitoring of milling train performance and has the potential to advance the understanding of the key parameters affecting extraction, leading to better process control and more consistent extraction outcomes.

Fig. 4—Validation plot for online pol extraction at Mulgrave Central Mill.

A typical 24 hour trend for calculated online pol extraction is shown in Figure 5. This trend shows that, across this period, relatively constant pol extraction of around 97% was achieved.

However, the graph does show particular examples where extraction has dropped by up to 2–3% before returning to the average extraction value.

These variations are attributed to a step decrease in cane quality (with no or little change in pol%bagasse) and the return of the extraction value back to the average reflects a return to better quality cane in the following consignment.
Currently, Mulgrave Central Mill uses NIR determined prepared cane pol to fibre ratio to determine milling train maceration levels, where the maceration\%cane fibre is varied within a defined operating range depending on the measured quality of incoming cane.

This is an example of a feed forward control system, whereas the application of real time online pol extraction data provides a potential feed forward maceration control system.

In an analogous fashion, online pol extraction predictions were developed and assessed at the Costa Pinto Mill during the 2008 season.

Calibration statistics for the CAS and BAS equations are shown in Table 2. There were a number of significant challenges to overcome in order to replicate the system that had been developed in Australia at Mulgrave Central Mill.

In particular, the equations used on the CAS and BAS systems were initially developed and constructed using Australian methods and data.

As expected, Costa Pinto Mill uses slightly different analytical procedures and sampling methods, which by definition will lead to slightly poorer agreement with the NIR data (i.e. higher SEP values).

The ECLs have been calculated from Australian data which include processes such as automated juice sampling and fully audited laboratory methods. The corresponding Costa Pinto data were generated by manual sampling and, as such, an increased sampling error and therefore increased ECL was expected.

The magnitude of acceptable ECL errors has not yet been determined and will require more data and larger populations of cane scanned in order to better represent them.
Table 2—Calibration equations and performance statistics for Costa Pinto Mill CAS and BAS installations.

<table>
<thead>
<tr>
<th>CAS parameter</th>
<th>SEP</th>
<th>Error control limit</th>
<th>Slope</th>
<th>Bias</th>
<th>( R^2 )</th>
<th>Range</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pol%juice</td>
<td>0.45</td>
<td>0.38</td>
<td>0.89</td>
<td>-0.15</td>
<td>0.78</td>
<td>12.3–20.5</td>
<td>330</td>
</tr>
<tr>
<td>Pol%cane</td>
<td>0.41</td>
<td>0.32</td>
<td>0.86</td>
<td>-0.09</td>
<td>0.75</td>
<td>10.6–17.0</td>
<td>330</td>
</tr>
<tr>
<td>Brix%juice</td>
<td>0.43</td>
<td>0.38</td>
<td>0.84</td>
<td>-0.12</td>
<td>0.78</td>
<td>15.8–23.0</td>
<td>330</td>
</tr>
<tr>
<td>Brix%cane</td>
<td>0.39</td>
<td>0.32</td>
<td>0.81</td>
<td>-0.07</td>
<td>0.75</td>
<td>13.5–18.9</td>
<td>330</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BAS parameter</th>
<th>SEP</th>
<th>Error control limit</th>
<th>Slope</th>
<th>Bias</th>
<th>( R^2 )</th>
<th>Range</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture%bagasse</td>
<td>0.75</td>
<td>1.07</td>
<td>0.80</td>
<td>0.01</td>
<td>0.74</td>
<td>44.8–52.0</td>
<td>145</td>
</tr>
<tr>
<td>Pol%bagasse</td>
<td>0.22</td>
<td>0.22</td>
<td>0.79</td>
<td>0.02</td>
<td>0.65</td>
<td>1.5–3.8</td>
<td>145</td>
</tr>
<tr>
<td>Fibre%bagasse</td>
<td>0.83</td>
<td>1.13</td>
<td>0.65</td>
<td>0.04</td>
<td>0.76</td>
<td>44.3–52.4</td>
<td>145</td>
</tr>
</tbody>
</table>

Further difficulties in drawing direct conclusions between the two installations are due to the differences in tracking systems employed. The tracking system is a critical element of online pol extraction determination since any measure of extraction requires the analysis of cane and bagasse from the same input cane. This cannot occur simultaneously due to the time lag involved along the milling train, but this time lag can be determined approximately by monitoring the progress of dye through the milling train. The measured time delay is used to synchronise CAS and BAS response for the same cane parcel. At Mulgrave Central Mill, cane is delivered to the mill in individual consignments which can be traced back to individual farms and blocks. As such, there is little difference in cane quality across several measurements within single consignments. Conversely, at Costa Pinto, the cane being crushed may have been sourced from several farms/blocks and mixed prior to milling, thereby increasing the variability in the pol extraction results from consecutive measurements.

In order to validate the online pol extraction measurement, a set of 24 samples was collected for complete cane and bagasse analysis (Figure 6). These samples were identified using a BSES tracking system (NCS Tracking) from CAS to BAS. The results were very good with 95% of NIR data appearing within 1 unit of the lab extraction value. This level of accuracy is more than adequate for application across process monitoring and control functions. Further, the validation results provide confidence that the variation shown within a typical 24 hour trend for NIR calculated pol extraction is real (Figure 7).
Fig. 7—Typical online pol extraction trend for a continuous 24 hour period at Costa Pinto Mill.

Despite the fact that these results have not been generated across large numbers of samples, there are important trends that are apparent. The results for NIR calculated online pol extraction are very similar at both sites, demonstrating that the technique is applicable across any milling train and is a robust measurement despite existing differences between the mills and their milling trains. Based on the similarities observed, we conclude that the measurement itself does not appear to be adversely affected by variations in cane variety, harvesting methods or the mill preparation of shredded cane.

Further, the authors expect that similar measurements should be applicable to any milling or diffusion extraction process, providing the ability to generate real time pol extraction. Access to this data will allow a mill to better understand pol extraction trends and to determine various optimised mill settings and maceration strategies which importantly can be altered in real time, in response to variations in the incoming cane supply and the observed extraction trends.

**Online lignin determination**

Since BAS installations must be located at the end of the milling train, they are ideally located for the real time analysis of bagasse which could be potentially employed for value adding processes other than as a boiler fuel. Bagasse has potential feedstock applications for many downstream applications including lignocellulosic applications, furfural production, lignin applications (Doherty et al., 2008) and others (Banerjee and Panday (2002). With this in mind, it was decided to explore the potential of BAS installations to serve as fibre or biomass analysers for parameters of interest to other processes. The starting point for this examination was the determination of lignin content, as it was envisaged that these data could have applications within lignocellulosic processing as well as impacting on the quality of bagasse as a boiler fuel for energy and cogeneration processes.

In 2006, eleven bagasse samples were sampled from Mulgrave Central Mill, analysed for lignin content and matched with existing NIR scans from the BAS instrument. They were further
characterised using a FOSS XDS laboratory NIR instrument at BSES Indooroopilly. A further 21 bagasse samples were characterised by laboratory NIR spectra only. The NIR scans from both instruments were pooled to develop an initial calibration.

This was an admittedly small data set which was potentially prone to overfitting, but was considered sufficient to generate a calibration which could provide indicative trends but not high quality quantitative data.

Table 3—Calibration equation and performance statistics for the lignin equation built from Mulgrave Central Mill bagasse samples.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SEC</th>
<th>Error control limit</th>
<th>Mean</th>
<th>Std Dev</th>
<th>R²</th>
<th>N</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignin % dry matter</td>
<td>0.09</td>
<td>0.11</td>
<td>16.46</td>
<td>2.56</td>
<td>0.99</td>
<td>43</td>
<td>10.60–18.75</td>
</tr>
</tbody>
</table>

This equation was used without validation and, as such, the precision and accuracy of the predictive equation are unknown. This renders the data generated as qualitative only and capable of indicating trends rather than providing quantitative data.

Figure 8 shows the equation applied to the Mulgrave Central Mill BAS installation within a 24 hour period during 2009, and is representative of the variation observed during any such period.

The online trend indicates considerable lignin variation within the bagasse, and that there are observable step changes in lignin content occurring between cane consignments.

Additionally, there is good clustering of lignin results within individual consignments and good sample definition. These are encouraging results and will be further developed, along with other equations for potential online biomass analysis.

![Typical online lignin content trend for a continuous 24 hour period at Mulgrave Central Mill.](image)
The relative trends in lignin content were examined by determining the unweighted arithmetic mean lignin value for all data observed, and dividing the individual values obtained by this value to produce a range of mean centred results. Using this calculation, a value of 1.0 indicates a result which was the same as the overall mean.

The cane supply at Mulgrave Central Mill is tracked from the field to the factory, thereby allowing the allocation of each bagasse scan to individual farms, blocks and varieties. This permits the analysis of lignin content across multiple varieties, crop classes and environmental situations, as well as permitting cross-correlations with productivity data. When applied to a continuous 2 week operation at Mulgrave Central Mill which covered some 1600 individual cane consignments during the early part of the 2009 season, an indication was gained of the variation in lignin content across cane variety and crop class.

Figure 9 shows the mean centred lignin content data for this period, and also indicates the tonnages of each variety crushed and the relative standard deviation for each of the variety averages. This shows that, across all varieties, the total variation was +/− 20% from the mean. The variation within varieties was approximately half of that and was of a similar magnitude for most varieties, irrespective of the tonnages processed. This tends to indicate that there are meaningful differences between lignin content for Australian commercial sugarcane varieties, and that the variation might be enough to warrant consideration of the intended use for the bagasse. Further, such data allow the mill to more accurately value bagasse for different downstream options. One possible scenario might see bagasse of higher lignin content deliberately used as boiler feed material, with lower lignin content material diverted to lignocellulosic digestion or fermentation systems where reduced lignin content may reduce process difficulties. In this way, online NIR data would be used to direct bagasse in a way which would maximise benefits to the sugar mill.

The ability to determine lignin content by NIR methods also has implications for plant breeding processes, especially with increasing interest in the development of energy canes for both cogeneration and for lignocellulosic biofuel/chemical production. Such methods could be applied at earlier stages of selection to identify varieties with desirable cellulose and lignin contents that are suitable for application as energy canes. More work is needed to improve the performance of this NIR calibration, but initial results are promising.
Conclusion

Online NIR systems have been developed in different configurations for the analysis of cane, sugar and bagasse process streams. They offer tremendous advantages for the continuous, real time provision of analytical data which can be used for quality, process control and payment situations. These data are backed up by laboratory analysis in order to continuously validate and track NIR performance. Recently developed applications of NIR methods have been described for the prediction of sugar and bagasse parameters which can provide significant benefits to the sugar mill.

Acknowledgements

The authors would like to thank all those who have assisted with the sampling and analysis of data presented in the paper. Particular thanks go to Mulgrave Central Mill staff (Glenn Pope, Jeff Snoad and Nadine Thomas), Paul Naylor (BSES), Viviane Paulenas (P. A. Sys Engenharia e Sistemas, Brazil), Rodrigo de Campos (P. A. Sys Engenharia e Sistemas) and Luis Fernando Antunes (Cosan S.A.) for their assistance in sample collection and analysis for the BAS work program, and Tracy Hay (Horizon Science) and Graham Butland (Mossman Mill) for assisting with sampling and analysis to support the SAS work program. The authors would also like to thank Cosan S.A. management and Costa Pinto Mill staff for providing a suitable site and significant support for the trial of CAS and BAS instruments.

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APPLICATION DE TECHNOLOGIES PROCHE INFRAROUGE (NIR) POUR L'ANALYSE DES CANNE, DE LA BAGASSES ET DU SUCRE ROUX POUR AMÉLIORER LES PERFORMANCES

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Résumé
BSES LIMITED a longtemps été associé au développement et a la commercialisation de la technologie NIR pour l'industrie sucrière; son savoir-faire comprend le développement variétal, les utilisations au laboratoire et en ligne dans l'usine. Ce papier retrace le développement de systèmes NIR en ligne avec FOSS Pacific, pour l'analyse en temps réel des cannes, de la bagasse et du sucre; on décrit une gamme d'applications actuellement appliquée dans les usines sucrières. Le système d'analyse de la canne (CAS) a été développé principalement pour mesurer la teneur en fibres en temps réel d'un lot de canne pour le paiement. Cela évite de se servir de chiffres basés sur des moyennes: le paiement est base sur la qualité du lot lui-même. CAS utilise un instrument FOSS Direct Light 5000 avec des systèmes auxiliaires développés pour la présentation de l'échantillon, l'analyse des données et l'intégration avec les systèmes de contrôle du moulin. On a aussi développé des systèmes pour les cendres, matière sèche, pol et Brix pour la canne, le jus, et le sucre commercial en canne (CCS). Les résultats provenant de ces étalonnages ont été utilisés avec succès pour tester la fiabilité aux laboratoires, pour obtenir des indices de qualité de canne à sucre, pour mettre en œuvre des stratégies de contrôle automatisé, pour développer des systèmes de paiement alternatif et fournir des données sur les exploitations individuelles, permettant des solutions ciblées pour les zones avec des problèmes de productivité. Basé sur cette plate-forme, les analyses en ligne de la bagasse (BAS) et du sucre (SAS) ont été mises au point. Le BAS permet un meilleur contrôle pour l’alimentation des chaudières. Lorsqu'il est lié à un CAS sur le train de moulins, les effets du réglage des moulins, de la macération et de la qualité de la canne sur l'extraction sont déterminés en temps réel, permettant le développement de stratégies visant à optimiser l'extraction. Les étalonnages SAS sont utilisés pour surveiller et contrôler les processus critiques dans la production de LoGlCane™, le premier sucre du monde avec un index glycémique faible, qui a été commercialisé en Australie en 2009. Le développement de systèmes NIR en ligne dans les usines sucrières a améliore la qualité du paiement et des stratégies de contrôle, ce qui serait impossible a partir de données normales de laboratoire. Presque 30 systèmes ont été installés dans le monde et de nouvelles applications pour le NIR en ligne continuent à être développées par les utilisateurs existants en conjonction avec BSES et FOSS.
IMPLEMENTACIÓN DE TECNOLOGÍAS DE INFRARROJO CERCANO EN LÍNEA (NIR) PARA EL ANÁLISIS DE CAÑA, BAGAZO Y AZÚCAR CRUDO EN INGENIOS PARA MEJORAR EL DESEMPEÑO

Por

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PALABRAS CLAVE: Espectroscopía NIR, Análisis en Línea, Análisis de Bagazo, Análisis de Azúcar, Control de Proceso.

Resumen

BSES LIMITED tiene una larga trayectoria en el desarrollo y comercialización de tecnología NIR para aplicaciones de la industria azucarera que cubren mejoramiento varietal, laboratorios y aplicaciones en la fábrica. Este trabajo recorre el desarrollo de sistemas en línea NIR con FOSS Pacific para el análisis en tiempo real de caña, bagazo y azúcar, describiendo un rango de aplicaciones usadas en ingenios. El sistema de análisis de caña (CAS) fue desarrollado en principio para medir en tiempo real el contenido de fibra de la caña para fines de pago. Esto posibilita el pago basado en la calidad global en lugar de aplicar supuestos a partir de cifras promedio. El CAS usa un instrumento FOSS Direct Light 5000, con sistemas auxiliares desarrollados para presentación de la muestra, análisis de datos e integración con los sistemas de control fabril. Posteriormente se desarrollaron aplicaciones del CAS para cenizas, materia seca, pol y brix tanto en caña como en jugo y para el cálculo del CCS. Los datos de estas calibraciones han sido utilizados para auditar los laboratorios de las fábricas, derivar los índices de calidad de caña, implementar estrategias de control, desarrollar sistemas de pago alternativos y suministrar datos sobre parcelas y fincas individuales permitiendo soluciones específicas para áreas con problemas de productividad. Con base en esta plataforma se desarrollaron sistemas para análisis de bagazo en línea (BAS) y análisis de azúcar en línea (SAS). Las mediciones BAS pueden suministrar caracterizaciones de bagazo basadas en calidad, aptas para control por adelanto de las estaciones de calderas. Cuando se conecta con un sistema CAS, en el mismo tren de molinos, los efectos de los ajustes, control de imbíbición y calidad de caña en la extracción de pol, se determinan en tiempo real, posibilitando el desarrollo de estrategias para maximizar extracción. Se usan calibraciones con SAS para monitorear y controlar procesos críticos en la producción de LoGlcane™, el primer azúcar en el mundo con bajo índice glicémico que fue liberado y comercializado en Australia en 2009. El desarrollo de sistemas de medición en línea NIR para ingenios azucareros ha generado el establecimiento de estrategias de calidad, pago y control, las cuales no hubieran sido posibles con el uso de datos de laboratorio normales. Casi 30 sistemas se han instalado a nivel mundial, y se están desarrollando aplicaciones adicionales para la información NIR en línea por parte de los usuarios existentes, en conjunto con BSES y FOSS.
EVAPORATION PROCESS IMPROVEMENT USING PRECALCULATED VALUES FOR JUICE INJECTION FLOW TO FIFTH EFFECT

By

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KEYWORDS: Effective Heat Transfer Area, Juice Injection, Syrup Concentration, Evaporation Process.

Abstract

This work presents a method for improving the evaporation train performance through a pre-calculated value for injection of clarified juice at the last effect. Previously, when the concentration of syrup was above set point, the juice injection valve remained fully open causing an upset in the stability of levels of the last effect vessels as well as in the temperatures. With measurements of juice flow going to the pre-evaporators, saturated vapour flow, temperatures, as well as effective heat transfer areas (EHTAs), values for the outcomes of each effect as well as condensate flows are calculated. In order to estimate vapour bleeding, the EHTA for each effect is calculated through heat transfer coefficients, estimated condensate flows and measured vapour and juice temperatures. EHTAs and the area of the calandria tubes in contact with steam must match and this is the criterion to estimate condensate flows. Computed values come directly from mass and energy balances over the evaporator set as a whole. Temperature corrected values for latent heat and heat capacity at constant pressure at each effect are used. Factory tests using the syrup flow calculated to control the juice injection valve at the fifth effect demonstrated operation with less overshoot in vapour and juice temperatures on last effect, stability of levels of the last effect vessels, and the brix of the syrup became more stable. These improvements show that this model of the evaporation process yields a value for the flow of syrup that is useful to make the juice injection valve dependent not only on the concentration of the syrup but also on the performance of the whole evaporator set. As the syrup flow increases, more clarified juice can be injected into the final effect and vice versa, and less juice is injected as the syrup flow decreases.

Introduction

Motivated by the optimisation of the evaporation station, the investigation group started to develop concentration profiles for all vessels involved. They discovered that the fourth effect vessel always reached up to 73 brix, meanwhile the output of the last effect was being diluted to 50–55 brix. The reason was that the valve controlling the injection of clarified juice opened 100% in a very short time, even though the evaporation throughput was minimal. The temperature and the amount of the juice injected caused instability in the level, syrup concentration oscillations and reduced the capacity of the fourth and fifth effect vessels.

Evaporation station description

There are two trains of evaporators at La Unión Sugar Mill, one for the raw sugar line and the other for the white sugar line. Each set consists of nine vessels. The white sugar line takes juice only from the first mill, and the rest of the juice and imbibition water go to the raw sugar evaporator line.

Juice is pumped into the first effect from a separate tank for each line. To this effect, the exhaust steam is added in parallel, that is, to the four vessels from the same source as shown in Figure 1. The liquor concentrated in the first effect is sent to the feed of the second effect, and so on through all five effects. Inside each effect the juice is fed in series from one vessel to the following.
Fig. 1—Vapour and juice flow diagram.
Traditional brix control applied

The control used to maintain the concentration of the syrup at a constant value, usually 65 Bx, is located at the end of the evaporators. A sample of the syrup comes out from a fixed point, its measured value (DT) is taken to a proportional plus integral control block which acts on two automatic valves whose control logic to maintain the given set point is as follows:

- If the measured brix is above the set point, the controller acts on the clarified juice injection control valve to the entrance of the last evaporator, governing clarified juice injection to reduce the concentration, or
- If the syrup brix is below set point, the controller acts on the syrup recirculation valve, also on the last evaporator, which recycles syrup back to the inlet of the last effect to evaporate it again, so the brix set point will be reached.

The regulation of these valves is done one at a time, which means that the valves will never be acting at the same time, if the injection valve is regulating, the syrup recirculation valve will be closed and vice versa.

The model-based brix control

A limit was imposed on the juice injection valve to make its 100% opening correspond to the maximum calculated syrup flow observed, which was around 60 kg/s. If the evaporation throughput diminished for any reason, the valve would follow the new limit (closes a corresponding percentage) regulating clarified juice injection to the fifth effect.

For about half an hour on two different days, brix samples were obtained from consecutive vessels to build the brix profiles shown in Tables 1 and 2, at the same time the new control was applied. These do not show any abnormal concentration in the 4th effect as would have been if the profile were done for example half an hour earlier, as can be seen in Figures 3 and 6, when there were periods of syrup brix below set point as well as signs of instability in the rest of the graphs.

<table>
<thead>
<tr>
<th>Table 1—Concentration profile along the evaporator set 04–05–2009 at 14:36.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation with injection valve limiting</td>
</tr>
<tr>
<td>-----------------------------------------</td>
</tr>
<tr>
<td>1C</td>
</tr>
<tr>
<td>2C</td>
</tr>
<tr>
<td>3C</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2—Concentration profile along the evaporator set 05–05–2009 at 10:32.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation with injection valve limiting</td>
</tr>
<tr>
<td>-----------------------------------------</td>
</tr>
<tr>
<td>1C</td>
</tr>
<tr>
<td>2C</td>
</tr>
<tr>
<td>3C</td>
</tr>
<tr>
<td>4C</td>
</tr>
<tr>
<td>5C</td>
</tr>
<tr>
<td>6C</td>
</tr>
</tbody>
</table>

All of the other brix profiles done by the investigation group showed a strayed pattern in the 4th effect with concentrations greater than 70 brix.

The graphs from Figure 2 to Figure 4 show the behaviour of the process variables involved when the control was applied for 48 minutes from 14:14 to 15:02 on 04/05/09, during the time the concentration profile of Table 1 was performed.

Figure 2 shows stabilisation of the levels in vessels 5, 6, 7 and 8 fifteen minutes after the controller started to work. Figure 3 shows stabilised syrup concentration, the regulation applied to the injection valve as well as total effective heat transfer area stabilisation. Figure 4 shows the absence of overshoots on the temperatures in vessels 6, 7 and 8 ten minutes after the control was applied (vessel 9 was being washed at the time).
The graphs from Figure 5 to Figure 7 show the behaviour of the process variables involved when the control was applied for almost an hour, from 10:24 to 11:21 on 5–05–09.
The effects on the performance of the evaporator set are greater on the experience the following day. During this time the concentration profile of Table 2 was performed and the stabilisation on levels is evident in Figure 5. The cycling of the syrup recirculation valve with unregulated juice injection valve is shown in Figure 6 for the period immediately before the application of the control, when the PID control was not able to control the process, coincidentally
with instability of the last effect level (vessel #9).

Of course, it is possible that the PID control was not properly tuned and it acted as an ON-OFF control. Other experiences were performed anyway on those last days of the sugarcane harvest, but were few because the cane supply was low. These results are not shown here because no brix profiles like those of Tables 1 and 2 were collected. The experiences could not be made when the syrup recycling valve was opened, and it was necessary to wait for the juice injection valve to open in order to apply the controller.

**Some comments on effective heat transfer areas**

A very important concept in the development of this model is that of EHTA, because it supplies the criteria to estimate, at any time, the amount of vapour bleeding to the evaporator set. The concept has to be refined since the heat transfer coefficients of the evaporators at La Union Sugar Mill are in the process of being measured this coming harvest, and the values used are the standards found in literature. The temperature differences were also too large and logarithmic mean temperature differences should be used. However, its immediate consequence is to show which effect is being bled and to what amount, since otherwise those areas were totally oversized as compared to those not being bled and proportions between effective and ‘real’ (calandria tubes areas) are kept.

**Conclusions**

- The proposed model offers a good approximation of the vapour bleeding effects on the evaporation train.
- The advantages of continuous instead of traditional batch operation come mainly from the fact that these kinds of simple models can be applied for control, which lead to simple and better operation.
- The equation found (24), computes the flow of syrup with the advantage that this value is not affected by the level regulation control on the last effect, as the flow of syrup being measured is obviously affected.
- Introduction of the controlled clarified juice into the process accelerates the dynamics in order to achieve steady state conditions on this naturally stable process. On equation (4), \( \tau = \frac{V}{F_{op}} \approx 6 \text{ min} \) is visibly reduced, as can be observed in Figure 4, by just keeping syrup flow as constant as possible (with help of the clarified juice to remove variations of flow), since clarified juice brix at the entrance of first effect seldom varies, once imbibition has been set, unless wash water from crystallisers is discharged.

**Acknowledgments**

Thanking is not enough to acknowledge the scientific atmosphere that supported this investigation. The initiative came from CARTIF, then it crystallised on a course on semi-physical models with phenomenological substrate to the staff of engineers by PhD Hernán Alvarez. Thanks are owed also to Ing. Carlos Rene Cifuentes of the industrial division, to the instrumentation engineering manager Ing. Estiven Recinos, and finally to the evaporation plant group of engineers: Inga. Claudia Barrientos, Ing. Milton Cifuentes, Ing. Omar Escobar, Ing. Edgar Ochoa and Ing. Otto Paau.

**REFERENCE**

A model for the evaporator set

A model was proposed to calculate the effective heat transfer area by means of the total heat transferred, the heat transfer coefficient and the vapour-juice temperature differentials. One of the by-products of these calculations was the amount of juice not evaporated from each effect which, in the case of the last effect, resulted in the amount of syrup produced and the capacity of governing the clarified juice injection valve with this predicted value.

Model assumptions

- By watching the syrup leaving the final effect, it was evident that it was not too viscous, therefore its properties were still very close to those of the water. So it was decided to assume that heat capacities of juice were those of water and only after watching the results could it be decided what corrections should be made. Otherwise, brix at each vessel should be measured to adjust heat capacities. It was found that the model worked and, after looking for precision, we found that with a brix span of 10 °Bx the heat capacity difference between juice coming and leaving a vessel was less than 5% as computed on internet site http://www.sugartech.co.za/heatcapacity/index.php. In this way, uncertainties coming from brix variations were avoided.

- Mass and energy balances were stated assuming no accumulations or losses of energy and/or matter on vessels, that is, we assumed stability in temperatures and levels. However, for the first effect only, a transient term was included, just to get an idea of the improvements achieved when the controlled variable (clarified juice to fifth effect) is added to the equations, which obviously is a feedback term because it was calculated in terms of the syrup flow which in turn is calculated from values of clarified juice and saturated vapour flow.

Measurements already on site, and those added for our goals, were all steam flows (before and after vapour bleeding), all juice flows into and out of each effect as well as all vapour, juice and condensate temperatures.

Process flows around evaporator station (kg/s)

- $F_E$ Exhaust Steam
- $F_{1F}$ 1st effect vapour flow
- $F_{1F}'$ 1st effect vapour flow after vapour bleeding
- $F_{2F}$ 2nd effect vapour flow
- $F_{2F}'$ 2nd effect vapour flow after vapour bleeding
- $F_{3F}$ 3rd effect vapour flow
- $F_{3F}'$ 3rd effect vapour flow after vapour bleeding
- $F_{4F}$ 4th effect vapour flow
- $F_{IP}$ Juice flow to pre evaporator
- $F_{1D}$ Juice flow from 1st effect
- $F_{2D}$ Juice flow from 2nd effect
- $F_{3D}$ Juice flow from 3rd effect
- $F_{4D}$ Juice flow from 4th effect
- $F_{5D}$ Juice flow from 5th effect

Temperatures (°C)

- $T_E$ Exhaust steam temperature
- $T_{1F}$ 1st effect temperature
- $T_{2F}$ 2nd effect temperature

\[ T_{3F} \] 3rd effect temperature
\[ T_{4F} \] 4th effect temperature
\[ T_{5F} \] 5th effect temperature
\[ T_j \] Juice temperature going to pre-evaporator
\[ T_2 \] Juice temperature going from pre-evaporator
\[ T_3 \] Juice temperature going from 2nd effect
\[ T_4 \] Juice temperature going from 3rd effect
\[ T_5 \] Juice temperature going from 4th effect
\[ T_6 \] Juice temperature going from 5th effect
\[ T_{cE} \] Exhaust steam condensate temperature
\[ T_{c1F} \] 1st effect condensate temperature
\[ T_{c2F} \] 2nd effect condensate temperature
\[ T_{c3F} \] 3rd effect condensate temperature
\[ T_{c4F} \] 4th effect condensate temperature

**Parameters**

- \( C_{p,Tx} \): Heat capacity at constant pressure at temperature \( T_x \) (kJ/kg/°C)
- \( \lambda_{T_x} \): Latent heat of vaporisation at temperature \( T_x \) (kJ/kg)

In this work the correlations given in Table 3 were used to calculate heat capacity at constant pressure \( (C_{p,Tx}) \) and latent heat of vaporisation \( (\lambda_{T_x}) \).

**Table 3**—Correlation for latent heat of vaporisation, enthalpy, and heat capacity of condensates (Smith et al., 2001).

<table>
<thead>
<tr>
<th>Property ((P_p))</th>
<th>(a_0)</th>
<th>(a_1)</th>
<th>(a_2)</th>
<th>(a_3)</th>
<th>(a_4)</th>
<th>(R^2)</th>
<th>Temperature range ((^\circ C))</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \lambda )</td>
<td>2500.7</td>
<td>-2.3173</td>
<td>-0.0004</td>
<td>-5*10^{-06}</td>
<td>-3*10^{-08}</td>
<td>1</td>
<td>40 to 180</td>
</tr>
<tr>
<td>( C_{PW} )</td>
<td>4.1586</td>
<td>0.0006</td>
<td>-6*10^{-06}</td>
<td>5*10^{-08}</td>
<td>1</td>
<td>40 to 180</td>
<td></td>
</tr>
</tbody>
</table>

where \( P_p = a_0 + a_1 T + a_2 T^2 + a_3 T^3 + a_4 T^4 \)

**Development of the model**

Transfer area for the first effect is calculated from the expression used to define convection heat transfer:

\[
A_{2F} = \frac{F_E \lambda_E}{U_{1F}(T_E - T_2)} \tag{1}
\]

where \( F_E \) is exhaust steam flow measured through the condensates produced, \( \lambda_E \) is latent heat of vaporisation of water at exhaust steam temperature \( T_E \), \( T_2 \) is juice temperature from first effect, and \( U_{1F} \) is the heat transfer coefficient of first effect.

To determine the flow exiting first effect vessels, an energy balance equation is used on the juice side:

\[
\rho V C_{p2} \frac{dT_2}{dz} = \rho F_{c2} \lambda_{c2} - \rho F_{c2} C_{p2} T_2 - \rho F_{c2} \lambda_{c2} + Q \tag{2}
\]

where \( Q \) is the convection heat, namely \( UA[LMTD] \). On the vapour side:

\[
\rho V_{c2} C_{p,c2} \frac{dT_{c2}}{dz} = \rho F_{c2} \lambda_{c2} - \rho F_{c2} C_{p,c2} T_{c2} = Q \tag{3}
\]
From mass balance equation, we made the simplifying assumption that the flow of vapour \( F_E \) is of the same value as the flow of condensates used in the previous equation. Assuming also \( V_{CE} \), the amount of condensate remaining in the calandria to be 0 we obtain from (3) an expression for \( Q \) and substituting this into (2), after rearranging terms, we get:

\[
\frac{V}{F_{EP}} \frac{dT_2}{dt} + T_2 = \frac{F_{IP} C_{P1}}{F_{EP} C_{P2}} T_1 - \frac{F_E C_{P2}}{F_{EP} C_{P2}} T_{cE} + \frac{F_E C_{P2} T_{cE}}{F_{EP} C_{P2}} - \frac{F_{IP} A_{1F}}{F_{EP} C_{P2}}
\]

(4)

This is an equation of the form:

\[
\frac{dy}{dt} + y(t) = Kx(t)
\]

(5)

where \( \tau = \frac{V}{F_{op}} \approx 2 \) min (volume of calandria is roughly 9 m\(^3\) and flow of juice from first effect is 4.5 m\(^3\) per minute),

whose integrating factor is:

\[
p(t) = \exp \int \frac{dt}{\tau} = e^{\frac{t}{\tau}}
\]

(6)

and the solution is:

\[
y(t) = y_0 e^{-\left(\frac{t - \tau}{\tau}\right)} + \frac{K}{\tau} \int_{t_0}^{t} e^{\frac{t - \tau}{\tau}} x(t) dt
\]

(7)

As soon as three times \( \tau \) (\( \approx 6 \) min.), steady state conditions exist. However, on closed loop, this time will be diminished substantially and (4) can be simplified by:

\[
F_E \lambda_E + F_{IP} C_{P1} T_{L1} = F_{IP} \lambda_{1F} + F_{oP} C_{P2} T_{2} + F_E C_{P2 E} T_{cE}
\]

(8)

From mass balance equation, we get \( F_{IP} = F_{oP} - F_{op} \) so Eq. No. (8) becomes an expression to calculate \( F_{op} \):

\[
F_{op} = \frac{F_{IP} \left( \lambda_{1F} - C_{P2 E} T_{2} \right) - F_E \left( \lambda_E - C_{P2 E} T_{cE} \right)}{\left( \lambda_{1F} - C_{P2 E} T_{cE} \right)}
\]

(9)

This equation can easily be checked for two extremes.

1. In the case \( F_{op} \) turns out to be zero we have all juice transformed into vapour:

\[
F_E \left( \lambda_E - C_{P2 E} T_{cE} \right) = F_{IP} \left( \lambda_{1F} - C_{P1} T_{L1} \right)
\]

(10)

2. If \( F_E \) is too small, we would have no evaporation which means: \( F_{IP} = F_{oP} \), the approximation \( C_{P1} \approx C_{P2} = C_{P} \) as usual, and substituting these two expressions into (9) to yield the known expression for heating a liquid:

\[
F_E \left( \lambda_E - C_{P2 E} T_{cE} \right) = F_{IP} C_{P} \left( T_2 - T_{L1} \right)
\]

(11).
Transfer area for second effect or Duplex is calculated the same way, except that care must be taken because the first effect vapour flow that enters into the vessels is not anymore \( F_{oP} - F_{oP} \) and has to be measured because of vapour bleeding. By means of gauging condensate tanks for exhaust steam as well as for first effect vapour, in the experiment the following relationship has been found:

\[
F_{1F}' = 0.6 F_E
\]  

(12)

and

\[
A_{2F}' = \frac{0.6 F_E \lambda_{4F}}{U_{2F}(T_{2F} - T_a)}
\]  

(13)

At this point, use of the concept of EHTA is starting to be important, as explained at the end of the main body of the paper. To measure the flow of vapour bleeding, we would have to make major changes in the distribution of tanks and tubes at the bottom of the evaporator set, because at this time they are mixed and pumped to the boiler. At other times, we also tried to measure the vapour, but the problem was with the sensors, since changes of pressure were too small to be measured. What is being proposed is that the model has to be calibrated constantly because the flow of clarified juice \( F_{iP} \) and the flow of Exhaust Steam \( F_E \), have different time-scale variations. In this experiment, the values (0.6, 0.33, and 1) were used to take account of vapour bleeding, but it will necessarily have to be changed according to the comparison criteria, that is, comparing EHTAs (effective heat transfer areas) computed with the areas of the tubes of heat exchangers in contact with steam. In future experiments, maybe this can be automated by setting up a range of valid variations of EHTA as compared with ‘real’ values of the sum of the areas of the tubes of the calandria.

By means of similar expressions to (8) and (9), we get the output flow of second effect:

\[
F_{oD} = \frac{F_{oP}(\lambda_{2F} - C_{P2} T_a) - 0.6 F_E (\lambda_{4F} - C_{P41F} T_{c1F})}{(\lambda_{2F} - C_{P2} T_a)}
\]  

(14)

This is the flow of juice to the 3rd effect vessels. To determine vapour flow of the second effect (later, the same procedure was applied to first effect), we compared on stable conditions the effective area of third effect, which was around 13,000 m², to the measured area of the heat exchanger tubes, roughly 4600 m², and observed an approximate 3 to 1 ratio which means that 66% vapour bleeding was made to this effect. Thus:

\[
F_{2F}' = 0.33(F_{oP} - F_{oD})
\]  

(15)

The effective area for the third effect as well as the juice flow are computed from the following equations:

\[
A_{3F} = \frac{0.33(F_{oF} - F_{o2F}) \lambda_{2F}}{U_{2F}(T_{2F} - T_a)}
\]  

(16)

\[
F_{oD} = \frac{F_{oP}(\lambda_{3F} - C_{P3} T_a) - 0.33(F_{oP} - F_{oD})(\lambda_{2F} - C_{P41F} T_{c1F})}{(\lambda_{2F} - C_{P2} T_a)}
\]  

(17)
Vapour bleeding on third effect was ignored by mistake (see Figure 1), but coincidently $T_5$ was improperly installed, as shown on simulation stage (not included in this paper because it was a simple excel sheet), compensating for the mistake, so the equation remains as:

\[
F_{GF}^c = F_{OF}^c - F_{GF}^F
\]  
(18)

\[
A_{GF} = \frac{F_{GF}}{U_{GF}(T_{GF} - T_B)}
\]  
(19)

\[
F_{OF}^c = \frac{F_{DF}(\lambda_{GF} - C_{PC4F}T_4) - F_{GF}(\lambda_{GF} - C_{PC4F}T_{cGF})}{(\lambda_{GF} - C_{PC4F}T_B)}
\]  
(20)

\[
F_{GF}^c = F_{OF}^c - F_{GF}^F
\]  
(21)

\[
A_{GF} = \frac{F_{GF}}{U_{GF}(T_{GF} - T_B)}
\]  
(22)

\[
F_{OM} = \frac{F_{OF}(\lambda_{GF} - C_{PC4F}T_4) - F_{GF}(\lambda_{GF} - C_{PC4F}T_{cGF})}{(\lambda_{GF} - C_{PC4F}T_B)}
\]  
(23)

After doing all substitutions, we get for $F_{OM}$:

\[
F_{OM} = \sum_{j=1}^{17} K_j F_{IP} + \sum_{j=1}^{28} K_j' F_{IP}^F
\]  
(24)

where $F_{IP}$ is juice flow and $F_{IP}^F$ exhaust steam,

\[
\tau_i = \prod_{j=1}^{2} \frac{\lambda_{GF} - C_{PI}T_i}{(\lambda_{GF} - C_{PI}T_i + 1)T_{i+1}}
\]  

and

\[
\tau_j = \prod_{i=0}^{4} \frac{\lambda_{GF} - C_{PC4I}T_{CIF}}{(\lambda_{GF} - C_{PC4I}T_{CIF} + 1)T_{i+1}}
\]
PREDETERMINATION DU JUS INJECTE DANS LE CINQUIÈME EFFET POUR AMÉLIORER L’ÉVAPORATION

Par
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MOTS-CLEFS: Transfert de Chaleur Effectif, Injection de Jus, Concentration du Sirop, le Processus d’Évaporation.

Résumé
Ce travail présente une méthode pour améliorer la performance des évaporateurs par l’injection prédéterminée de jus clarifié dans le dernier effet. Auparavant, lorsque la concentration du sirop était au-dessus de la norme, la vanne d’injection de jus restait complètement ouverte, affectant la stabilité des niveaux des dernières effets ainsi que les températures. On mesure les débits de jus aux pré évaporateurs, le débit de vapeur, les températures, ainsi que les surfaces pour le transfert de chaleur (EHTAs), pour calculer la performance de chaque effet ainsi que les débits des eaux condensées. Afin d’estimer les prélèvements de vapeur, la EHTA pour chaque effet est calculée par l’intermédiaire de coefficients de transfert de chaleur, des débits d’eaux condensées, et les températures de la vapeur et du jus. Les EHTAs et la surface des tubes de la calandre en contact avec la vapeur doivent correspondre et c’est le critère pour estimer les débits des eaux condensées. Les valeurs calculées proviennent directement de bilans de masse et d’énergie pour le train complet d’évaporateur. Les températures sont corrigées pour les effets des chaleurs latentes à pression constante pour chaque effet. Des essais en usine avec le sirop calculé pour contrôler la vanne d'injection du jus au cinquième effet ont donné une consommation de vapeur, des températures et un Brix plus stables au dernier effet. Ces améliorations montrent que ce modèle d’évaporation donne de bons résultats pour le train d’évaporateurs. Comme le débit de sirop augmente, plus de jus clarifié est injectée dans l'effet final et vice versa.
USO DE LA MEJORA DEL PROCESO DE EVAPORACIÓN PRECALCULADOS VALORES PARA LA INYECCIÓN DE JUGO EL FLUJO AL EFECTO QUINTO

Por
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PALABRAS CLAVE: Transferencia de Calor Efectiva Espacio, Jugo de Inyección, Jarabe de concentración, Proceso de Evaporación.

Resumen
Este trabajo presenta un método para mejorar el rendimiento del tren de evaporación por medio de valores pre-calcados del jugo claro de inyección en el último efecto. Con anterioridad, cuando la concentración de la meladura estaba arriba de la consigna, la válvula de inyección de jugo acostumbraba quedarse todo el tiempo abierta ocasionando inestabilidad en los niveles de los vasos en los últimos efectos así mismo en las temperaturas. Con mediciones del flujo de jugo a los pre-evaporadores, flujo de vapor saturado, temperaturas y las áreas efectivas de transferencia de calor AETCs se calculan los productos de cada efecto así como los flujos de condensados. Para estimar las sangrías o extracciones el AETC para cada efecto se calcula por medio de los coeficientes de transferencia de calor, flujos de condensado estimados y temperaturas medidas de jugo y vapor. AETCs y las áreas de los tubos de la calandria en contacto con el vapor deben ser iguales y este es el criterio para estimar los flujos de condensados. Los valores calculados salen directamente de balances de masa y energía sobre el tren de evaporadores como un todo. Se usan valores corregidos por temperatura del calor latente y la capacidad calorífica a presión constante en cada efecto. Mediante pruebas en campo usando el flujo de meladura calculado para controlar la válvula de inyección de jugo en el quinto efecto se consiguió una operación más estable en las temperaturas del vapor y del jugo del último efecto, estabilidad en los niveles de los vasos de los últimos efectos y el brix de la meladura más estable. Estas mejoras muestran que este modelo del proceso de evaporación produce un valor para el flujo de meladura que es útil para hacer que la válvula de inyección de jugo claro no solo dependa de la concentración de la meladura sino también de la producción total del tren de evaporadores. Mientras el flujo de meladura aumenta, más jugo clarificado se puede inyectar en el quinto efecto y viceversa, se inyecta menos jugo si el flujo de meladura disminuye.
DRD—DEDINI REFINADO DIRETO (DEDINI DIRECT REFINED) IMPROVEMENTS IN REFINED AND CRYSTAL WHITE SUGAR PRODUCTION

By

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KEYWORDS: Crystal White Sugar, Direct Refined Sugar.

Abstract
In addition to its application in the production of granulated refined sugar directly from clarified cane syrup in sugar mills, the Dedini Direct Refined (DRD-Dedini Refinado Direto) can be applied as an improvement in white sugar plants and conventional refineries, allowing production of white sugar from syrups of very high colour. This paper describes the tests conducted with DRD applied to the clarification of high colour syrup obtained from the juice of a new variety of sugar cane (RB92579), widely planted in the northeast of Brazil, which has great productivity but characteristically produces a strongly coloured juice. A study of the relationship between the colour in the final crystal sugar or refined sugar and the colour of the syrup, comparing results obtained in several parts of Brazil and references in the literature, is also presented. This paper also points out the excellent performance of DRD in tests carried out in Brazilian northeast sugar mills, in which it successfully performed the decolourisation of several highly coloured syrups obtained from sugarcane mixtures with different RB92579 content.

Introduction
Between 2005 and 2007 Dedini Indústria de Base S/A (Olivério and Boscariol, 2006 and 2007) presented a new process for granulated refined sugar production directly from syrup, called Direct Refined Process (DRD- Dedini Refinado Direto) (Figure 1). One of the key factors of this process is the capacity of the resins used in this process to retain coloured compounds.

The Brazilian northeast sugar mills experience difficulties in the production of white crystal sugar when processing the new cane variety RB92579. It was considered that the DRD process could assist the mills to produce white sugar. Although this variety of sugarcane is highly productive for the conditions of this region, it has high quantities of coloured compounds that lead to the production of high colour syrups, and consequently, highly coloured crystals. Mantelatto (2005) presented a vast bibliographic review and a detailed study of the process of mother liquor migration to the crystal, correlated with the velocity of crystallisation. If the objective is to obtain white sugar from highly coloured syrup, it is evident that a syrup treatment to reduce the level of colour is necessary. The DRD process together with good sugar house procedures can be important tools to obtain low colour white crystal sugar.

This paper presents the results of DRD pilot plant tests running with the highly coloured syrup after clarification. Colour loading versus saturation curves and the performance of resin columns operating with syrup containing different percentages from the cane variety RB92579 are also discussed. Finally, correlations of crystal colour obtained as a function of syrup colour for sugar mills in different regions of the country are provided, which are compared with data in the literature, and with the sugar obtained from juice decolourised by the DRD process. A simulation of
the use of the DRD process is presented, as a guide in the production of white crystal sugar (<150 IU) for highly coloured syrup.

Materials and methods
The DRD process: refined sugar without a refinery
A schematic of the DRD process is shown in Figure 1. It is designed to produce refined sugar directly from clarified syrup without the need to produce raw sugar and then remelt and recrystallise it as is the practice in a conventional refinery.

In the DRD process, the main unit operation is syrup decolourisation. This operation is performed by high capacity ionic exchange resins. To evaluate the behaviour of these resins in the decolourisation process of highly coloured syrup, tests were performed in a pilot unit, presented in Figures 2 and 3 at the sugar mills Usinas Caeté and União Indústria S/A respectively, located in São Miguel (AL) and Primavera (PE), both in the northeast of Brazil.

The steps involved in the decolourisation process were developed in partnership with Rohm and Haas. It comprises a system of three stages in series (DRD1, DRD2 and DRD3) of ionic exchange resins designed to work under the characteristic conditions of clarified syrup. The basic characteristics of the DRD resins are presented in Table 1.
Fig. 3—Photograph of the DRD pilot plant.

Table 1—Basic characteristics of the ion exchange resin utilised in the DRD process.

<table>
<thead>
<tr>
<th>Properties</th>
<th>DRD1</th>
<th>DRD2</th>
<th>DRD3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matrix</td>
<td>Polystyrene</td>
<td>Acrylic</td>
<td>Polystyrene</td>
</tr>
<tr>
<td>Functional group</td>
<td>Sulfonic acid</td>
<td>Quaternary ammonium</td>
<td>Quaternary ammonium</td>
</tr>
<tr>
<td>Ions form as shipped</td>
<td>Na⁺</td>
<td>Chloride</td>
<td>Chloride</td>
</tr>
<tr>
<td>Total exchange capacity</td>
<td>≥1.8 eq/L resin (Na⁺ form)</td>
<td>≥0.8 eq/L resin (Cl⁻ form)</td>
<td>≥1.0 eq/L resin (Cl⁻ form)</td>
</tr>
<tr>
<td>Moisture holding capacity</td>
<td>47–54% (Na⁺ form)</td>
<td>66–72% (Cl⁻ form)</td>
<td>58–64% (Cl⁻ form)</td>
</tr>
</tbody>
</table>

Operation

The pilot plant operated with clarified syrup with a brix of around 60 to 65 and 70–75°C. Firstly, the syrup passed through a sand pressure filter in down flow at a pressure around 2.5 bar, to remove gross particles as well as turbidity compounds to avoid plugging of the resin beds with suspended solids. The filtered syrup passed through the three columns in the up flow direction. The purpose of the first resin column is to soften the syrup, the second to perform decolourisation and the third to perform final polishing to guarantee syrup of the necessary quality for efficient crystallisation. The pilot plant operated with a mean flow of 350 L/h with operating cycles at around 30 h. At the end of each cycle, the resins went through a regeneration process with caustic brine solution (10% NaCl and 0.02% NaOH) and returned to operate in a new decolourisation cycle. The resins were submitted to various operating cycles, in which it was possible to establish that their efficiency in the removal of colour was maintained at around 50 to 70%.

At the sugar mill Usina Caeté, the influence of the cane variety RB92579, a source of high colour juice as seen in Figure 4, on the performance of the system of resins was evaluated.

Fig. 4—Clarified juice from cane variety RB92579.
Results and conclusions

Figure 5 shows the influence of the quantity of cane variety RB92579 on the syrup colour. It can be observed that the increase in colour of the syrup can be linked with the proportion of RB92579 processed. Figure 6 shows the influence of the quantity of cane variety RB92579 on the A-sugar colour. It can also be observed in Figure 6 that the increase in colour of the A sugar is partly due to the increase in the cane RB92579 processed and the high level of colour in the syrup. The high and variable colour loading makes it difficult to maintain the colour of the A white sugar below 150 IU. It was proposed to use the DRD process to assist the production of A white sugar with a consistent colour level equal to or below 150 IU. The results of using the DRD process to reduce syrup colour during the processing of RB92579 are presented.

Tables 2 and 3 present an example (cycle 14) of DRD syrup decolourisation in the Caeté Sugar and Alcohol Mill. The DRD pilot plant ran for a total of 22 cycles. The DRD system operated with the press sand filter filled with sand, followed by the cationic column (DRD1), first anionic column (DRD2) and a second anionic column (DRD3).
Table 2—Data for DRD syrup processing at Caeté Sugar and Alcohol Mill, samples 52 to 56, cycle 14 of 22.

<table>
<thead>
<tr>
<th>Variety</th>
<th>10/18/2008</th>
<th></th>
<th></th>
<th>0/19/2008</th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tonnes</td>
<td>%</td>
<td>Tonnes</td>
<td>%</td>
<td></td>
<td></td>
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<tr>
<td>RB 92579</td>
<td>1538</td>
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<td>1374</td>
<td>14.73</td>
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<td></td>
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<td>SP 813250</td>
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<tr>
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<td>230</td>
<td>250</td>
<td>2138</td>
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</tr>
<tr>
<td>RB 867515</td>
<td>1663</td>
<td>18.07</td>
<td>601</td>
<td>6.44</td>
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</tr>
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NI: It's not informed

Start: 16:40 Date: 10.18 2007
End: 19:50 Date: 10.18 2008

Sample 52

<table>
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<tr>
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<th>FO</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>Colour removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brix (%)</td>
<td>58.00</td>
<td>54.40</td>
<td>53.20</td>
<td>51.20</td>
<td>49.60</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>5.74</td>
<td>7.68</td>
<td>7.65</td>
<td>7.81</td>
<td>6.58</td>
<td></td>
</tr>
<tr>
<td>Colour (IU)</td>
<td>10 118</td>
<td>7347</td>
<td>7111</td>
<td>5317</td>
<td>2793</td>
<td>72.40%</td>
</tr>
<tr>
<td>Optical density (420 nm)</td>
<td>1101</td>
<td>745</td>
<td>594</td>
<td>522</td>
<td>727</td>
<td></td>
</tr>
<tr>
<td>Purity</td>
<td>84.05</td>
<td>85.03</td>
<td>85.38</td>
<td>85.41</td>
<td>86.10</td>
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</tr>
<tr>
<td>Polarisation</td>
<td>47.75</td>
<td>46.26</td>
<td>45.42</td>
<td>43.73</td>
<td>42.70</td>
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Sample 55

<table>
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<th>FO</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>Colour removal</th>
</tr>
</thead>
<tbody>
<tr>
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<td>55.60</td>
<td>56.40</td>
<td>55.20</td>
<td>53.60</td>
<td>52.00</td>
<td></td>
</tr>
<tr>
<td>pH</td>
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<td>5.89</td>
<td>5.90</td>
<td>6.16</td>
<td>6.80</td>
<td></td>
</tr>
<tr>
<td>Colour (IU)</td>
<td>9650</td>
<td>9928</td>
<td>9663</td>
<td>9604</td>
<td>6400</td>
<td>33.68%</td>
</tr>
<tr>
<td>Optical density (420 nm)</td>
<td>318</td>
<td>73</td>
<td>162</td>
<td>328</td>
<td>182</td>
<td></td>
</tr>
<tr>
<td>Purity</td>
<td>90.91</td>
<td>89.37</td>
<td>88.20</td>
<td>87.77</td>
<td>90.15</td>
<td></td>
</tr>
<tr>
<td>Polarisation</td>
<td>50.54</td>
<td>50.41</td>
<td>48.69</td>
<td>47.58</td>
<td>46.88</td>
<td></td>
</tr>
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Sample 56

<table>
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<th>FO</th>
<th>F1</th>
<th>F2</th>
<th>B</th>
<th>F4</th>
<th>Colour removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brix%</td>
<td>62.40</td>
<td>48.40</td>
<td>52.00</td>
<td>52.00</td>
<td>54.80</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>5.85</td>
<td>7.07</td>
<td>6.87</td>
<td>7.52</td>
<td>7.63</td>
<td></td>
</tr>
<tr>
<td>Colour (IU)</td>
<td>9425</td>
<td>8855</td>
<td>8591</td>
<td>8341</td>
<td>4643</td>
<td>50.74%</td>
</tr>
<tr>
<td>Optical density (420 nm)</td>
<td>966</td>
<td>766</td>
<td>655</td>
<td>* 593</td>
<td>879</td>
<td></td>
</tr>
<tr>
<td>Purity</td>
<td>84.22</td>
<td>83.61</td>
<td>83.64</td>
<td>83.45</td>
<td>83.83</td>
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<tr>
<td>Polarisation</td>
<td>52.55</td>
<td>40.47</td>
<td>43.49</td>
<td>43.40</td>
<td>45.94</td>
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Sample 53

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<thead>
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<th>F2</th>
<th>B</th>
<th>F4</th>
<th>Colour removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brix%</td>
<td>48.40</td>
<td>53.20</td>
<td>52.00</td>
<td>56.00</td>
<td>56.60</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>5.77</td>
<td>5.91</td>
<td>5.88</td>
<td>6.19</td>
<td>6.73</td>
<td></td>
</tr>
<tr>
<td>Colour (IU)</td>
<td>10 292</td>
<td>9605</td>
<td>9284</td>
<td>8779</td>
<td>5612</td>
<td>45.47%</td>
</tr>
<tr>
<td>Optical density (420 nm)</td>
<td>959</td>
<td>229</td>
<td>493</td>
<td>68</td>
<td>202</td>
<td></td>
</tr>
<tr>
<td>Purity</td>
<td>85.82</td>
<td>88.35</td>
<td>88.28</td>
<td>88.24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polarisation</td>
<td>39.85</td>
<td>47.00</td>
<td>48.79</td>
<td>49.44</td>
<td>49.06</td>
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</tr>
</tbody>
</table>

Sample 54

<table>
<thead>
<tr>
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<th>FO</th>
<th>F1</th>
<th>F2</th>
<th>F1</th>
<th>F4</th>
<th>Colour removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brix%</td>
<td>52.80</td>
<td>53.20</td>
<td>56.80</td>
<td>58.00</td>
<td>55.60</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>5.88</td>
<td>6.17</td>
<td>6.24</td>
<td>6.53</td>
<td>7.05</td>
<td></td>
</tr>
<tr>
<td>Colour (IU)</td>
<td>11 110</td>
<td>10 006</td>
<td>9594</td>
<td>9100</td>
<td>5388</td>
<td>51.50%</td>
</tr>
<tr>
<td>Optical density (420 nm)</td>
<td>885</td>
<td>570</td>
<td>635</td>
<td>591</td>
<td>728</td>
<td></td>
</tr>
<tr>
<td>Purity</td>
<td>88.68</td>
<td>88.91</td>
<td>88.36</td>
<td>88.46</td>
<td>89.66</td>
<td></td>
</tr>
<tr>
<td>Polarisation</td>
<td>46.83</td>
<td>47.30</td>
<td>50.19</td>
<td>51.31</td>
<td>49.85</td>
<td></td>
</tr>
</tbody>
</table>
Table 3 combines the colour data for samples 52 to 56 of Table 2 and includes the volumes of syrup passing through the pilot plant. The abbreviations in both tables include:

- $V =$ syrup feed volume (cumulative);
- $F_0 =$ colour of syrup feed to the sand press filter;
- $F_1 =$ output syrup colour from the sand press filter (filled with sand);
- $F_2 =$ output syrup colour from cationic column DRD1 (filled with 200 L resin);
- $F_3 =$ output of first anionic column DRD2 (filled with 200 L resin); and
- $F_4 =$ output of second anionic column DRD3 (filled with 150L of DRD3 resin).

<table>
<thead>
<tr>
<th>Volume of ion exchange resin (L)</th>
<th>200</th>
<th>200</th>
<th>150</th>
</tr>
</thead>
<tbody>
<tr>
<td>CYCLE 14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V$ (L)</td>
<td>320</td>
<td>2048</td>
<td>2704</td>
</tr>
<tr>
<td>$F_0$ (IU)</td>
<td>1009</td>
<td>2048</td>
<td>2704</td>
</tr>
<tr>
<td>$F_1$ (IU)</td>
<td>7347</td>
<td>8885</td>
<td>10 006</td>
</tr>
<tr>
<td>$F_2$ (IU)</td>
<td>7111</td>
<td>8591</td>
<td>9594</td>
</tr>
<tr>
<td>$F_3$ (IU)</td>
<td>5317</td>
<td>8341</td>
<td>9100</td>
</tr>
<tr>
<td>$F_4$ (IU)</td>
<td>2793</td>
<td>4643</td>
<td>5388</td>
</tr>
</tbody>
</table>

Figure 7 illustrates the reduction in colour as the syrup progresses through the DRD process. Clarified syrup from a flotation clarifier with a colour of 8856 IU was sampled as it passed through each resin column. In this example, the colour of the final decolorised syrup was 1846 IU, a removal efficiency exceeding 70%.
Table 4 shows example data (cycle 2) for the DRD plant decolourising syrup at União Indústria Sugar and Alcohol Mill.

### Table 4 — Data for DRD syrup processing at União Indústria Sugar and Alcohol Mill – Samples 08 to 13, Cycle 2 of 25. DRD Experiments, União Industria

<table>
<thead>
<tr>
<th>Variety</th>
<th>1/11/2008</th>
<th>1/12/2008</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tonnes</td>
<td>%</td>
</tr>
<tr>
<td>RB 92579</td>
<td>396</td>
<td>7.17</td>
</tr>
<tr>
<td>SP 813250</td>
<td>355</td>
<td>6.44</td>
</tr>
<tr>
<td>SP 791011</td>
<td>96</td>
<td>1.75</td>
</tr>
<tr>
<td>SP 716949</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>SP 784764</td>
<td>2138</td>
<td>38.76</td>
</tr>
<tr>
<td>VAT90-212</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>SP 813250ED</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>RB 867515</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>N1</td>
<td>2530</td>
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NI: It is not informed

<table>
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<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>Colour removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brix%</td>
<td>52.00</td>
<td>58.00</td>
<td>57.20</td>
<td>55.20</td>
<td>46.40</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>6.4</td>
<td>8.6</td>
<td>8.8</td>
<td>8.4</td>
<td>9.1</td>
<td></td>
</tr>
<tr>
<td>Colour (IU)</td>
<td>12947</td>
<td>7956</td>
<td>8217</td>
<td>4158</td>
<td>3156</td>
<td>86.77%</td>
</tr>
<tr>
<td>Optical density (420 nm)</td>
<td>743</td>
<td>423</td>
<td>356</td>
<td>234</td>
<td>189</td>
<td></td>
</tr>
<tr>
<td>Purity</td>
<td>89.50</td>
<td>93.51</td>
<td>93.49</td>
<td>94.20</td>
<td>90.73</td>
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</tr>
<tr>
<td>Polarisation</td>
<td>46.54</td>
<td>54.24</td>
<td>53.47</td>
<td>52.00</td>
<td>42.10</td>
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Start: 16:30 Date: 01/11/2008 Composite sample
End: 18:30

<table>
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<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>Colour removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brix%</td>
<td>59.20</td>
<td>54.40</td>
<td>56.80</td>
<td>54.40</td>
<td>58.00</td>
<td></td>
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<tr>
<td>pH</td>
<td>6.5</td>
<td>7.7</td>
<td>8.4</td>
<td>8.7</td>
<td>8.8</td>
<td></td>
</tr>
<tr>
<td>Colour (IU)</td>
<td>11282</td>
<td>8831</td>
<td>7518</td>
<td>4192</td>
<td>3235</td>
<td>71.33%</td>
</tr>
<tr>
<td>Optical density (420 nm)</td>
<td>623</td>
<td>386</td>
<td>351</td>
<td>185</td>
<td>130</td>
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<tr>
<td>Purity</td>
<td>87.24</td>
<td>88.53</td>
<td>88.16</td>
<td>89.58</td>
<td>88.83</td>
<td></td>
</tr>
<tr>
<td>Polarisation</td>
<td>51.64</td>
<td>48.16</td>
<td>50.07</td>
<td>48.73</td>
<td>51.52</td>
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Start: 20:30 h Date: 01/11/2008 Composite sample
End: 23:00h

<table>
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<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>Colour removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brix %</td>
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<td>62.40</td>
<td>62.00</td>
<td>62.40</td>
<td>64.80</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>5.81</td>
<td>5.77</td>
<td>5.69</td>
<td>6.42</td>
<td>6.76</td>
<td></td>
</tr>
<tr>
<td>Colour (IU)</td>
<td>9773</td>
<td>13816</td>
<td>14649</td>
<td>12984</td>
<td>7531</td>
<td>76.5%</td>
</tr>
<tr>
<td>Turbidity (420 nm)</td>
<td>1175</td>
<td>467</td>
<td>450</td>
<td>446</td>
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<td></td>
</tr>
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<td>Purity</td>
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<td>79.82</td>
<td>77.99</td>
<td>78.88</td>
<td>81.96</td>
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</tr>
<tr>
<td>Polarisation</td>
<td>54.45</td>
<td>49.81</td>
<td>48.36</td>
<td>49.22</td>
<td>53.11</td>
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</tr>
</tbody>
</table>

Start: 01:00 Date: 01/11/2008 Composite sample
End: 03:00 h
The DRD pilot plant ran for a total of 25 cycles. In this case, the DRD system operated with the press sand filter filled with sand and 150 L of DRD2 and 150 L of DRD3 anionic resin, followed of cationic column (DRD1), first anionic column (DRD2) and a second anionic column (DRD3). This option was possible because the factory had a syrup belt press filter after the syrup clarifier. Thus, the syrup feed in the DRD process had a low level of turbidity and solids in suspensions. This was done to aid syrup purification since the colour of the raw syrup was very high.

Table 5 was compiled with colour data from Table 4 together with the volumes of syrup fed through the columns.

**Table 5**—Variation of colour as a function of volumes of syrup feed. V = volumes of syrup feed; F0 = colour of syrup input to sand press filter; F1 = output of sand press filter (150 L DRD2 resin and 150 L DRD3 resin), F2 = output of cationic column (200 L DRD1), F3 = output of first anionic column (200 L DRD2), F4 = output of second anionic column (150 L DRD3 resin).

<table>
<thead>
<tr>
<th>Volume of ion exchange resin (L)</th>
<th>150 DRD2 + 150 DRD3</th>
<th>200</th>
<th>200</th>
<th>150</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle 2 V (L) Fo (IU) F1 (IU) F2 (IU) F3 (IU) F4 (IU)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>258</td>
<td>714</td>
<td>11 282</td>
<td>8831</td>
<td>7518</td>
</tr>
<tr>
<td>1854</td>
<td>3222</td>
<td>11 775</td>
<td>8280</td>
<td>8925</td>
</tr>
<tr>
<td>3734</td>
<td>4646</td>
<td>13 819</td>
<td>12 025</td>
<td>11 945</td>
</tr>
</tbody>
</table>

The graphs in Figures 8, 9, 10, and 11 present the results correlating the colour load absorbed by the resin system versus the volume of syrup fed into the columns in relation to the volume of resin, denominated by bed volumes (BV), and syrup colour as a function of the BVs in one of the cycles studied during the trials at Caeté Sugar and Alcohol Mill and União Indústria Sugar and Alcohol Mill, respectively.
Considering that the resins can operate up to 60–70% of saturation (see the load capacity of resins in Table 1), in the case of anionic resins on DRD it is possible, as can be seen in Figures 8 and 10, to operate with a colour load which could reach a level as high as 60 000–65 000 IU. This demonstrates the capacity to bear high rates of colour adsorption, even for syrup containing high initial colour loads.

As seen in Figures 8 and 10, the colour accumulated in the resins conforms to a linear behaviour with the BV fed to the columns. The different slopes of the curves indicate different load factors depending on the characteristics of the resin and also the affinity between colour compounds and functional group of the resins. The Figures thus obtained were used to design the system on an industrial scale.

In Figure 12, the colour removal efficiency values of the system are correlated as a function of the proportion of the cane variety RB92579 in the cane being supplied to the factory. As indicated by the data, the extra colour loading introduced by RB92579 has no effect on the colour removal efficiency of the resins. Moreover, it was observed that the resin system was capable of maintaining a removal efficiency in the range of 50 to 70%, even when processing this variety of cane with higher clarified juice colour.

It was shown that the DRD-Dedini system could be used successfully both as an aid in the production of white sugar and for the production of refined sugar by using clarified syrup as the feed to the decolourisation process.

To compare the levels of removal attained in the various colour removal processes in crystallisation, the colour of the sugar obtained was regressed against the colour of the syrup or liquor of the Brazilian sugar mills as follows:

(1) DRD System (Olivério and Boscariol, 2006 and 2007), refined sugar obtained from decolourised syrup: $y = 0.007 \times + 17.65$;
(2) Thompson et al. (2006) refined sugar;
(3) A white crystal sugar – Us. Mogiana: \[ y = 47.73 \cdot \exp (1.31 \cdot 10^{-4} \cdot x) \];
(4) White crystal sugar – Us Sta Isabel: \[ y = 19.96 \cdot \exp (2.10 \cdot 10^{-4} \cdot x) \];
(5) White crystal sugar – Us. Caeté: \[ y = 46.88 \cdot \exp (0.98 \cdot 10^{-4} \cdot x) \];
(6) White crystal sugar – Us. União Indústria: \[ y = 42.20 \cdot \exp (1.31 \cdot 10^{-4} \cdot x) \];
(7) Controlled cooling crystallisation of liquor obtained from raw sugar (VHP and VVHP) and cane syrup, (Mantelatto, 2005): \[ y = 0.0214 \cdot x + 8.80 \].

Fig. 10—Colour load accumulated in the ion exchange resins as a function of the bed volumes fed at União Sugar and Alcohol Mill. F1 = outlet of column DRD1; F3 = outlet of column DRD2; F4 = outlet of column DRD3.

Fig. 11—Colour of syrup as a function of bed volumes passed through the ion exchange columns at União Sugar and Alcohol Mill. F0 = clarified syrup colour; F1 = outlet of filter; F2 = outlet of column DRD1; F3 = outlet of column DRD2; F4 = Outlet of column DRD3.

The models were obtained considering the moving average of three points. As can be observed from the data presented in Figure 13, the colour removal factor in the crystallisation of juice coming from the DRD system was excellent, when compared with the other systems.
presented. As an example, the curve corresponding to União Indústria in Figure 13 indicates that the colour of the syrup must be about 8000 to 9000 IU to produce white crystal with a colour of 150 IU.

Finally, DRD technology proved to be an improvement to the white sugar process, even for high colour syrups. From the study conducted, in addition to the studies previously conducted (Olivério and Boscariol, 2006 and 2007), it could be concluded that the DRD system can be advantageously used both in the production of granulated refined sugar and for the production of white crystal sugar (colour < 150 IU).

![Graph showing colour removal efficiency](image1)

**Fig. 12**—Overall efficiency of colour removal by the DRD-Dedini system as a function of the proportion of cane variety RB92579 processed at Caeté Sugar and Alcohol Mill.

![Graph showing sugar colour vs syrup colour](image2)

**Fig. 13**—Variation in the colour of sugar as a function of the colour of syrup feed to the crystallisation process: DRD, Thompson et al. (2006), Mogiana Sugar and Alcohol Mill, Sta Isabel Sugar and Alcohol Mill, Caeté Sugar and Alcohol Mill, União Industria Sugar and Alcohol Mill and Mantelatto (2005).
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DRD—DEDINI REFINADO DIRETO (DEDINI DIRECT RAFFINÉ)
AMÉLIORATIONS POUR LA PRODUCTION DE SUCRE RAFFINÉ
ET DE SUCRE CRISTAL BLANC

Par

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MOTS-CLEFS: Sucre Crystal Blanc, Sucre Raffiné.

Résumé

EN PLUS de son application pour la production de sucre raffiné directement à partir de sirop de canne clarifié dans les usines a sucre, le Dedini Direct Raffiné (DRD-Dedini Raffiné Direto) peut être introduit pour améliorer la production du sucre blanc et l’opération des raffineries conventionnelles, permettant la production de sucre blanc à partir de sirops de couleurs très élevées. Ce papier décrit des essais concernant l’application du DRD pour la clarification de sirops de hautes couleurs obtenus à partir d’une nouvelle variété de canne (RB92579), populaire dans le nord-est du Brésil, qui a un bon rendement mais produit un jus fortement coloré. Une étude de la relation entre la couleur du cristal de sucre ou du sucre raffiné et celle du sirop, tout en comparant les résultats obtenus dans plusieurs régions du Brésil et les références dans la littérature, est présentée. Ce document souligne également l’excellente performance du DRD pendant des tests effectués dans les usines du Nord-est brésilien; le DRD a permis une bonne décoloration de sirops fortement colorées, obtenus à partir de cannes contenant différents pourcentages de B92579.
DRD—REFINADO DIRECTO DEDINI MEJORAMIENTO EN LA PRODUCCIÓN DE AZÚCAR BLANCO Y REFINADO

Por

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PALABRAS CLAVE: Azúcar Blanco, Azúcar Refinado Directo.

Resumen

ADemás de su aplicación en la producción de azúcar refinado directamente de meladura clarificada, el Refinado Directo Dedini (DRD-Dedini Refinado Direto) puede ser aplicado como un mejoramiento en las plantas de azúcar blanco y en las refinerías convencionales, permitiendo la obtención de azúcar blanco a partir de meladuras de color muy alto. Este artículo describe las pruebas realizadas con el DRD aplicado a la clarificación de meladura de alto color obtenida del jugo de una nueva variedad de caña (RB92579), sembrada ampliamente en el noreste de Brasil con alta productividad pero que produce jugo con alto color. Se presenta también un estudio de la relación entre color del azúcar blanco y refinado y el color de la meladura, comparando con los resultados obtenidos en varias partes de Brasil y con los reportados por la literatura. También se señala el excelente desempeño del DRD en pruebas realizadas en ingenios del noreste brasileño, donde se obtuvo exitosamente la decoloración de varias meladuras altamente coloreadas obtenidas de mezclas de caña con diferentes contenidos de RB92579.
SUCROSE LOSS IN STORAGE OF GREEN BILLET CANE

By

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KEYWORDS: Sugarcane, Loss, Deterioration, Temperature, Storage.

Abstract
Sucrose lost during storage of green billet cane was measured for different storage times and temperatures; in cane that was hand-cleaned before storage (2007) and in (normal) cane used just as delivered by combines (2008). The storage conditions were characterised by the time (hours) of storage within four temperature ranges: <17°C, 17–22°C, 22–27°C and >27°C, representing cold, cool, moderate and warm storage conditions. Within the four ranges, the sucrose loss in normal cane was 0.08, 0.13, 0.27 and 0.32% of the initial sucrose per hour; or an increase in the rate of sucrose loss of about 0.03% initial sucrose per hour per each °C temperature rise. Probably because of the higher enzymatic activity in tops and leaves, the losses in hand-cleaned cane were lower. Based on the developed equations, total sucrose loss in cane storage at a 10 000 t/day factory was estimated to be 1200 t in one eighty-day season. The temperature within cane stored in a factory cane yard and cane trailers was measured. Cane stored in trailers was found to cool overnight (6 pm to 6 am) on average by 0.3°C /h but the temperature of cane stored in piles increased by about 0.1°C/h. This was interpreted as evidence of substantial heat generation during cane storage. However, based on the measured overnight temperature profiles, it was concluded that the difference in sucrose loss between storage in trailers and cane piles alone is not large enough to justify conversion to trailers-only storage.

Introduction
Despite several previous studies (Clarke, 1991; Birkett et al., 1998; Godshall, 1999; Legendre et al., 2000; Eggleston, 2002), data on sucrose loss during cane storage in Louisiana have not been available. A program was therefore organised, with these guidelines set forth:

- measure sucrose loss directly, rather than its indicators, e.g. dextran, ethanol, mannitol, etc.;
- limit the study to green (un-burnt) billet cane;
- cover the range of temperatures and times relevant in Louisiana, viz. 5–35°C and 24 hours or less;
- determine cane weight changes in storage and include them in calculation of the sucrose loss;
- determine sucrose with HPLC rather than polarimetry to avoid errors from changing invert.

In 2007, the tests involved combine-harvested cane that was hand cleaned before storage and contained no leaves or tops while, in 2008, green billet cane was tested just as delivered by combine (normal cane).
Results

Sucrose loss in storage

Full detail of the procedures can be found in the online edition of ASSCT Journal (Saska et al., 2009). In each test, cane was randomly divided into three batches; one was crushed immediately, and two after storage at two different temperature regimes. All juice and bagasse was collected, weighed and analysed. An overall mass balance was performed, as well as mass balances on the cane components: water, fibre, sucrose and invert sugars.

Table 1—Average cane composition, before and after 24-hour storage. Combined data from 2007 (hand-cleaned cane) and 2008 (normal cane).

<table>
<thead>
<tr>
<th></th>
<th>Cold storage</th>
<th>Warm storage</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>Sucrose % cane (N=28)</td>
<td>12.7</td>
<td>12.5</td>
</tr>
<tr>
<td>Invert % cane (N=28)</td>
<td>0.6</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Sucrose % cane on average decreased, while, with few exceptions, invert sugar levels increased during storage (Table 1). Because of the slow heat transfer within billet cane, temperature of the cane (recorded with data loggers) varied in each experiment with time and could not be defined by a single value. In Figure 1, the recorded dimensionless cane temperature \((T - T_{\text{initial}})/(T_{\text{final}} - T_{\text{initial}})\) at two locations A and B within the storage container is plotted against time (test 6/2008, \(T_{\text{initial}} = 5^\circ\text{C}, T_{\text{final}} = 32^\circ\text{C}\)).

Fig. 1—Measured dimensionless temperature profiles (thick points) in cane storage, and a heat transfer model (thin line) applied to location A. \(\alpha\) is the thermal diffusivity of billet cane in \(\text{m}^2/\text{s}\) (test 6/2008)

For the purpose of fitting the data, the storage temperature was characterised by the time (hours) within four temperature ranges: \(<17^\circ\text{C}, 17–22^\circ\text{C}, 22–27^\circ\text{C} \text{ and } >27^\circ\text{C}\), representing cold, cool, moderate and warm conditions. The sucrose loss (in % initial) was defined as

\[
\Delta S = a_1 \cdot T_1 + a_2 \cdot T_2 + a_3 \cdot T_3 + a_4 \cdot T_4 \quad \text{Eq.1}
\]

where \(T_i\) is the time in hours within each of the four temperature intervals, respectively and \(a_i\) is the corresponding coefficient obtained by fitting the data. The coefficients represent sucrose weight loss (% initial) per hour in the four temperature intervals (Table 2).
Table 2—Measured sucrose loss per hour in stored green billet cane.

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>a_1</td>
<td>&lt;17</td>
<td>0.008</td>
<td>0.079</td>
</tr>
<tr>
<td>a_2</td>
<td>17–22</td>
<td>0.011</td>
<td>0.129</td>
</tr>
<tr>
<td>a_3</td>
<td>22–27</td>
<td>0.031</td>
<td>0.265</td>
</tr>
<tr>
<td>a_4</td>
<td>&gt;27</td>
<td>0.318</td>
<td>0.324</td>
</tr>
</tbody>
</table>

In normal cane, the measured sucrose loss was higher than in hand-cleaned cane. This may be at least in part due to higher enzymatic activity in tops and leaves than in the stalk. The scatter in the 2008 data in normal cane was larger than in 2007 (data not shown) because of greater heterogeneity of cane with trash. In the temperature range 17–27°C, the effect of temperature on sucrose loss is about 0.03% initial sucrose/°C.h. The recent data from Reunion (Corcodel and Mullet, 2007) fall mostly within this temperature range. Their reported sugar loss in green whole-stalk cane (1% per day) is about three times less than our results for green billet cane. As an example, for a factory storing 5000 t of cane overnight, eighty 12-hour storage periods per season, that is 960 hours in total, and equally distributed among the four temperature intervals (i.e. 240 hours below 17°C, 240 hours between 17 and 22°C, etc.), equation 1 predicts a loss of 1200 t sucrose in one eighty-day season, worth over $400 000.

**Temperature and heat transfer in stored billet cane**

In 2008, two cane trailers were fitted with temperature probes and data loggers. A total of 16 overnight periods were evaluated (Table 3) when the trailers were left in the field overnight loaded with cane. On average, the cane in the trailers cooled by 0.3°C/h, at about half the rate of the ambient temperature drop. In contrast, the temperature of cane in the factory yard (concrete slab) measured in 2007 increased in each test, on average by 0.1°C/h, despite the dropping night-time temperature, as the heat generated within cane exceeded the heat loss. For the temperature profiles listed in Table 3, the average overnight temperature of cane in piles is about 2°C higher than in the trailers. With a storage capacity 5000 t cane, the sucrose loss about 0.03 x 500 t sucrose x 2°C x 12 hours or about 3.5 t/day of sucrose higher. This difference alone may not be large enough to justify conversion to trailer-only storage, but the reported high cost of operating front-end loaders in cane yards may be enough to consider such investment.

In order to optimise temperature conditions in storage, heat transfer in stacked cane needs to be measured. An example in Figure 1 of the temperature profiles in cane storage at two locations (A = 4 and B = 40 cm above the container bottom) illustrates the time scale that it takes for the cane to heat up from ~5 to 32°C. A one-dimensional, semi-infinite slab model (thin line) applied to position A indicates thermal diffusivity in the range of 5x10⁻⁵ m²/s. Heat transfer modelling can in the future be used to assist the design of cane transport and storage and reduce sucrose losses.

Table 3—Average cane and air temperature profiles during 12-hour storage (6 pm to 6 am) in a factory cane yard and two cane trailers. Temperature of cane stored in piles increased overnight, while cane in trailers cooled.

<table>
<thead>
<tr>
<th>Sample type</th>
<th>Initial cane temperature, °C</th>
<th>Average temperature change °C/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane yard (2007, N=5)</td>
<td>18.3</td>
<td>Air: -0.42, Cane: 0.11</td>
</tr>
<tr>
<td>Trailer 1 (2008, N=7)</td>
<td>24.6</td>
<td>Air: -0.48, Cane: -0.34</td>
</tr>
<tr>
<td>Trailer 2 (2008, N=9)</td>
<td>25.1</td>
<td>Air: -0.53, Cane: -0.25</td>
</tr>
</tbody>
</table>
Acknowledgments

Funding from the American Sugar Cane League is gratefully acknowledged, as is the assistance from the Sugarcane Research Station and the St. Mary and Lula sugar factories.

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http://www.assct.org/journal/journal.htm

PERTES DE SACCHAROSE PENDANT LE STOCKAGE DES CANNES VERTES TRONCONNEES

Par

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MOTS CLEFS: Canne a Sucre, Pertes, Détérioration, Température, Stockage.

Résume

La perte de saccharose au cours du stockage de cannes vertes tronçonnées a été mesurée pour des stockages de différentes durées et à des températures différentes; des cannes nettoyées manuellement avant le stockage (2007) et des cannes livrées normalement par des moissonneuses (2008). Les conditions de stockage ont été caractérisées par le temps (heures) de stockage dans quatre plages de température: 17°C, 17–22°C, 22-27°C et > 27°C, qui représentent des conditions de stockage aux températures froides, fraîches, modérées et chaudes. Dans les quatre fourchettes, la perte de saccharose des cannes livrées normalement a été 0.08, 0.13, 0.27 et 0.32 % du saccharose initial par heure; ou une augmentation du taux de perte de saccharose de 0.03 % du saccharose initial par heure par chaque °C. Probablement en raison de l'activité enzymatique plus élevée dans les bouts blancs et les feuilles, les pertes pour les cannes nettoyées à la main ont été inférieures. Basé sur les équations développées, la perte totale de saccharose durant le stockage de la canne pour

une usine de 10 000 t/jour a été estimée à 1 200 t pendant une saison de quatre-vingt jours. La température au sein de la canne à sucre stockée sur la plate-forme et dans les remorques a été mesurée. La canne stockée dans des remorques refroidie pendant la nuit (6 h à 6 h) en moyenne de 0.3°C par heure, mais la température de la canne stockée en tas sur la plate-forme a augmentée de 0.1°C/h. Cela a été interprété comme une preuve d’un dégagement de chaleur substantiel au cours de ce stockage de la canne. Toutefois, selon les profils de température d’un jour à l’autre, il a été conclu que la différence de perte en saccharose entre stockage sur la plate-forme et dans les remorques n’est pas suffisante pour justifier la conversion vers un stockage en remorques seulement.

PÉRDIDAS DE SACAROSA EN EL ALMACENAMIENTO
DE CAÑA COSECHADA MECÁNICAMENTE EN VERDE

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PALABRAS CLAVE: Caña, Pérdida, Deterioro, Temperatura, Almacenamiento.

Resumen
Se midió la sacarosa perdida durante el almacenamiento de trozos de caña para diferentes tiempos y temperaturas; en caña que fue limpiada a mano antes de almacenarla (2007) y en caña tal como fue entregada por las cosechadoras (2008). Las condiciones de almacenamiento fueron caracterizadas por el tiempo (horas) de almacenamiento con cuatro rangos de temperatura: <17°C, 17–22°C, 22-27°C y >27°C, representando condiciones frías, frescas, moderadas y cálidas. Dentro de los cuatro rangos, la pérdida de sacarosa en caña normal fue de 0.08, 0.13, 0.27 y 0.32% de la sacarosa inicial por hora; o un incremento en la tasa de pérdida de sacarosa de cerca de 0.03% de la sacarosa inicial por hora y por cada °C de incremento de temperatura. Probablemente debido a la mayor actividad enzimática en hojas y cogollos, las pérdidas en caña limpiada a mano fueron menores. Con base en las ecuaciones desarrolladas, la pérdida total de sacarosa en almacenamiento de caña en una fábrica de 10 000 t/día fue estimada en 1200 t para una zafra de 80 días. Se midió la temperatua dentro de la caña almacenada en el patio y en vagones. Se encontró que la caña almacenada en vagones se enfrió en la noche (6 pm to 6 am) en promedio 0.3°C/h pero la temperatura de caña apilada en patio se incrementó cerca de 0.1°C/h. Esto se interpretó como una evidencia de generación sustancial de calor durante el almacenamiento. Sin embargo, con base en los perfiles de temperatura medidos durante la noche, se concluyó que la diferencia en la pérdida de sacarosa entre almacenamiento en vagones y en patio, por sí sola, no es suficientemente grande para pasar a almacenamiento sólo en vagones.
SPITTLEBUGS INJURY ON SUGARCANE
INCREASED SUGAR COLOUR

By

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KEYWORDS: Saccharum spp.,
Mahanarva fimbriolata, Clarification.

Abstract

SPITTLEBUGS may cause a reduction in sugarcane quality, problems with juice clarification and lower the VHP sugar quality by increasing phenol compounds and colour. A randomised complete-block design experiment with three replicates was conducted. The first factor tested was spittlebug injury to cane stalks with a control (0%) and different levels of infested stalks (15, 30 and 60%). The second factor tested was the timing of harvest; May-June and October of the 2007/2008 season. The highest spittlebug injury levels resulted in decreased sugar quality and reductions in brix, pol and pH and increased fibre, colour and total acidity. For clarification, better results were achieved in the second harvest period and demonstrated in a significant reduction in total acidity of extracted juice and low levels of phenol compounds and sugar colour. Spittlebug injury increased sugar colour. During May-June, the 30% level of spittlebug injury resulted in increases in phenol compounds (41%) and sugar colour (39%).

Introduction

The increase in green cane harvesting contributed to a significant increase in the population of Mahanarva fimbriolata (Stål) (Hemiptera: Cercopidae). Infestations caused by this pest affect cane quality (Gonçalves et al., 2003). The aim of this study was to evaluate the effect of spittlebugs on the quality of the raw material, the purification process, phenol concentrations and the colour of sugar.

Material and methods

The experiment was carried out at a commercial sugarcane area in Guariba, SP region, (Lat 21°21’S, Long 48°13’W) using a mechanically harvested 4th ratoon of variety SP80-1842 during the 2007/2008 season.

The study was arranged in a randomised complete-block design in a 4 x 2 factorial arrangement with three replicates. The first factor to test was the level of damage with healthy stalks (0%) and with 15, 30 and 60% infestation levels. The second factor to test was the two harvesting periods:

- May-June (when the crop age was 11 months, low temperature and dry soil conditions); and
- October (when the crop age was 14 months, with high rainfall and temperature conditions).

The composition of damaged stalks to simulate mechanical harvesting was in accord with Gonçalves et al. (2003).

The stalks were manually harvested, defoliated and topped at the apex bud and allocated to one of the four sample lots based on the infestation level. The juice was extracted by using a hydraulic press to press 500 g of disintegrated cane for one minute at 250 kg/cm² pressure to simulate the extraction of juice in roller mills (Tanimoto, 1964) for analysis and sugar production.
The cane and juice characteristics were determined with:

- Juice brix at 20°C and apparent sucrose by sacarimetric determination (Scheneider, 1979);
- Juice pH measured using a digital pH meter ‘Digimed DMPH–2’ from Tecnal, Brazil;
- Juice acidity expressed in g H₂SO₄/L and juice colour (Copersucar, 2001);
- Fibre is calculated from the brix and purity of the juice extracted by the hydraulic press and the wet and dry weights of the bagasse plug and juice purity (%) (Consecana, 2008);
- Moisture by drying cane bagasse at 65°C for 48 h and then weighing; and
- Total phenol compounds as described by the Folin and Ciocalteau (1927) method.

The extracted juice was reduced to 18 brix prior to purification. In the clarification process, 300 mg/L of phosphoric acid was added to the juice and the pH was corrected to 7.0 with cold lime at 6 Bé. The treated juice was then heated to boiling point and 2 mg/L of a flocculant (Mafloc 985) was added and the juice transferred to a 1 L graduated cylinder for decantation of the flocculated mud in a lamp-heated system. The mud settling rate, mud volume and added lime were recorded and the turbidity (transmittance at 620 nm), brix (Scheneider, 1979), colour (Copersucar, 2001) and pH of the clarified juice were determined.

Clarified juice with an average 16 brix, was concentrated to 60 brix effecting a rotating evaporator to produce syrup. This material was stored at –20°C until the next stage of crystallisation.

The massecuite was produced with adapted reactor with 5 L of capacity and control of temperature (61±2°C). The nucleation of crystals was made with seed process. Refined sugar (<0.5 mm) was added, to growth to 0.7–1.0 mm. After seeding, the process was conducted on metastable zone of supersaturation with feeding 60 brix syrup.

To optimise the crystal growth, the massecuite was put in a 2 L beaker with intermittent agitation by spatula at 1 min intervals. After massecuite temperature dropped from 60 to 55±2°C, the centrifugation was made to separate sugar and molasses with use of 1 kgf/cm² for 2 seconds of steam to clean sugar on start of process.

The crystals were previously drawn with forced ventilation (40°C) and agitation. After, for complete draw, the process continues in an oven (30°C), without air circulation, for 12 h. The production of VHP sugar was 300 g for each experimental parcel. On-product was made: a) ICUMSA colour (CTC, 2005); b) total phenol compounds: 26 g of sugar in 100 mL of distilled water and the method of Folin and Ciocalteu (1927) with adaptation, using 0.5 mL of extract. The data were expressed in mg of total phenol compounds per kg of sugar.

The data were submitted to ANOVA and means were compared by Tukey test (P=0.05). The significant quantities (% of damaged stalks) parameters were submitted to regression analysis (Banzatto and Kronka, 2006).

**Results and discussion**

The analysis of variance indicated that elevated spittlebug damage caused a reduction in brix (F=3.5110; P<0.05), pol (F=9.2224; P<0.01) and pH (F=18.9835; P<0.01) in juice and increased the level of Tanimoto fibre (F=5.7908; P<0.01). The reduction in quality of sugarcane by insects was observed by various studies including, for example, Gonçalves et al. (2003), Ravaneli et al. (2006) and Madaleno et al. (2008).

For regression analysis, it was observed that there was a reduction in quality mainly during the second period (Figure 1). Damaged stalks (30%) reduced brix by 3% in May–June; 6% in the first and 4% in the second period for pol; 0.5% and 2.3% between periods for pH; and increased by 5.5% for Tanimoto fibre in October.
For the clarification process, it was observed that the level of damaged stalks did not influence any of the analysis parameters. However, there were increases in sedimentation speed (P<0.05), lime volume used (P<0.01), pH of clarified juice (P<0.01) and turbidity (P<0.01) from May–June to October.

The spittlebug damaged stalks significantly reduced the sugar quality. There were increases in colour (P<0.01) and total phenol compounds. In the two harvest periods, more colour (P<0.01) and phenols (P<0.01) were found in May–June. This result might have been affected by the better purification process in October.

During the first harvest period, when the clarification process was not adequate, the sample of 30% damaged stalks resulted in a 41% increase in total phenol compounds and a 39% increase in sugar colour as shown in Figure 2.
Trade contracts (Amstar and Savannah Raw Sugar Contract), have been used since 1984, and include penalties for non-compliance with quality criteria that include sucrose content, moisture, ash, crystal size, dextran and colour (Chen and Chou, 1993).

Acknowledgments

The authors are thankful to Fundação de Amparo a Pesquisa do Estado de São Paulo (process no. 06/03005-0), Syngenta Proteção de Cultivos Ltda and Louis Dreyfus Commodities, São Carlos Mills for financial support, and Coordenação de Aperfeiçoamento de Pessoal de nível Superior for the doctoral fellowships.

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LES CANNES ATTAQUEES PAR LES «SPITTLEBUGS» DONNENT DES SUCRES DE COULEURS ELEVEES

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MOTS-CLEFS: Saccharum spp., Mahanarva fimbriolata, Clarification.

Résumé
Le «Spittlebug» peut causer une réduction de la qualité des cannes, des problèmes de clarification, et peut réduire la qualité de sucre VHP en augmentant les phénols composés et les couleurs. Une expérience basée sur des principes statistiques, avec trois réplicates a été effectuée. Le premier facteur testé a été le degré de l’attaque des «spittlebugs» sur la tige; on a choisi un contrôle (0%) et différents niveaux de tiges infestées (15, 30 et 60%). Le deuxième facteur testé était la date de la récolte; mai–juin et octobre de la saison 2007–2008. Les plus hauts niveaux de blessures par «spittlebugs» ont entraîné une diminution de la qualité du sucre, des réductions des brix, pol et pH et une augmentation de la fibre, de la couleur et de l’acidité totale. De meilleurs résultats ont été réalisés en clarification pendant la deuxième période de récolte; on a trouvé une diminution significative en acidité totale des jus et de faibles niveaux de phénols composés et une couleur de sucre plus basse. La présence du «Spittlebug» augmente la couleur du sucre. En mai et juin, le niveau de 30% de blessure a cause une augmentation des composés de phénol (41%) et de la couleur de sucre (39%).

INCREMENTO EN EL COLOR DEL AZÚCAR POR CAÑA DAÑADA POR SALIVAZO

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PALABRAS CLAVE: Saccharum spp., Mahanarva fimbriolata, Clarificación.

Resumen
El salivazo puede causar una reducción en la calidad de la caña, problemas en la clarificación de jugo y disminución de la calidad del azúcar de alta pureza por el incremento de compuestos fenólicos y el color. Se efectuó un diseño experimental de bloques completos al azar con tres repeticiones y el primer factor probado fue el daño a los tallos, con un control (0%) y diferentes niveles de infestación (15, 30 y 60%). El segundo factor fue el tiempo de cosecha, Mayo-Junio y Octubre de la zafra 2007–2008. Los mas altos niveles de daño resultaron en menor calidad del azúcar y reducciones en brix, pol, pH y en un incremento de fibra, color y acidez total. En clarificación, los mejores resultados se obtuvieron en el segundo periodo de cosecha, evidenciados en una reducción significativa en la acidez total del jugo extraído y menores niveles de compuestos fenólicos y color de azúcar. El daño por salivazo incrementó el color del azúcar. Durante Mayo-Junio, el nivel de daño del 30% resultó en incremento de compuestos fenólicos (41%) y de color del azúcar (39%).
BAGACILLO FLOTATION CELL

By

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KEYWORDS: Bagacillo Removal, Flotation.

Abstract
INCREASED sugarcane preparation to achieve better milling efficiency results in a significant increase in bagacillo in raw juice. For removal of the bagacillo, rotary screens and vibroscreens have gained much importance in the recent past. However, there is certain limitation for the removal of bagacillo as the screens do not allow the separation of fine bagacillo particles of size less than 0.32 mm. Raw juice generally contains some occluded air and the same when pressurised during pumping to juice heaters, gets dissolved at the pump delivery. Raw juice having dissolved air and heated up to 70°C, when released to atmosphere in a cell, causes flotation of the bagacillo. Such a concept was tried in a 150 t/h capacity sugar mill with very encouraging results.

Introduction
Bagacillo, the fine fibre component of bagasse produced due to increased cane preparation remains in the screened mixed juice. About 70–90% separation is observed with the existing static and rotary screens. Static and rotary screens are used extensively to screen fibre from juice. But static screens are less preferred and outdated due to their inconsistent performance. The particle cut-off size in a pilot rotary screen was found to be 0.32 mm. (Manson and Ames, 1982).

The residual bagacillo and other suspended matter lead to processing difficulties and finally affect adversely the quality of the product sugar (Crane et al., 2004). Saccharin in bagacillo imparts yellow colour by reacting with lime. Bagacillo can cause severe clogging problems in heat transfer equipment and centrifugals. Bagacillo is also sometimes found in product sugar. Hence, effective bagacillo removal before clarification will have a very significant benefit to produce good quality sugar. Recently, different filters have been developed to screen bagacillo content (Crane et al., 2004). But these filters are associated with high energy consumption and low availability due to the need for frequent cleaning at the rated juice flow.

The fine bagacillo particles in the juice have a propensity to entrap tiny air bubbles (Crane et al., 2004). This property of bagacillo helps in its separation through flotation. Further, the elevated temperature of juice releases dissolved air and the decreased viscosity results in effective flotation of bagacillo as scum in a flotation cell.

The flotation technique was tried in Deccan Sugars, a 3600 tcd sugar mill in Andhra Pradesh, India following double sulphitation process for the manufacture of plantation white sugar. Very encouraging results were obtained and are presented in this paper.

Description of the flotation cell
The flotation cell shown in Figure 1 is similar in construction to a syrup clarifier. The cell has a volume of 4.9 m³ and is operated at juice flow rate between 70 t/h to 126 t/h. The bagacillo flotation cell is placed before the liming and sulfitation process as illustrated in Figure 2. The scum is scraped by the top mounted scrapers driven by 0.4 kW motor. The scum collected in the annular chamber diverts onto the vibroscreen driven by a 1.1 kW motor, which screens bagacillo from scum. The screened bagacillo falls by gravity into the mud minger where mud from the Graver type juice clarifier is mixed with bagacillo before sending it to the rotary vacuum filter. Juice from the vibroscreen joins the juice stream for liming and sulfitation.
Results and discussions

The bagacillo content in the screened mixed juice before and after flotation cell was measured by separating the bagacillo using an 80 mesh (175 μm aperture) size screen from a 1000 mL mixed juice sample.

The fibre content was dried to equilibrium and measured to determine the bagacillo content in mixed juice. Twenty four samples were analysed in the course of the campaign to study the performance of the flotation cell. The results are shown in Figures 3, 4 and 5.

Bagacillo content in screened mixed juice before flotation was observed to be varying from 3 to 20 g/L. This residual bagacillo content may not be fully removed in the clarification process. As noted earlier, it is often found in the product sugar.

Considerable bagacillo separation was achieved through the flotation process. Bagacillo removal in the flotation cell varied from a minimum of 8.2% to a maximum of 64%. However, 20-35% bagacillo removal was consistently achieved in the flotation cell.

The purity of the juice was found to increase at the outlet of the flotation cell indicating separation of non-sucrose components through flotation. The brix of the juice was measured using a brix spindle and the pol was measured by a Schmitz and Hanson saccharimeter.
Separation efficiency could be further improved in the existing system with minor modifications such as increasing the volume of the bagacillo flotation cell. Introduction of a nano-bubbling generator into the flotation cell to improve the efficiency of the system is also under consideration. There is, however, a possibility of higher thermal losses in the flotation cell.

Fig. 3—Trend showing bagacillo content in screened mixed juice before flotation.

Fig. 4—Trend showing bagacillo removal efficiency of the flotation cell.

Fig. 5—Trend showing increase in juice purity with increase in bagacillo removal.
Conclusion

Through this study, it is clear that bagacillo separation through flotation is possible. The flotation cell along with diffusion system can also be installed before juice heating. Since there is no elevation of juice temperature for dissolved gases to be released, diffusion may help to impart efficient bagacillo separation.

Success of this system will increase the quality of sugar and improve heat transfer efficiency in the heat exchangers. Low efficiency juice heat exchangers can be replaced by heat exchangers having high turbulence and heat transfer coefficient.

Bagacillo flotation cell could be an economical solution to removing bagacillo content effectively. Further research and study into the mechanics of flotation is required to improve the efficiency of the flotation system.

REFERENCES


CELLULE DE FLOTTAISON POUR LA FOLLE BAGASSE

Par

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MOTS-CLEFS: Elimination de la Folle Bagasse, Flottaison.
Résumé

L’AUGMENTATION de la préparation des cannes pour atteindre une meilleure efficacité aux moulins se traduit par une augmentation significative de la folle bagasse dans le jus. Pour éliminer la folle bagasse on se sert de tamis rotatifs et vibratoires. Toutefois, il y a des limitations pour l'élimination de la folle bagasse comme les tamis ne permettent pas la séparation des particules de taille inférieure à 0,32 mm. Le jus contient généralement de l’air qui se dissout aux pompes. Le chauffage du jus contenant de l’air en solution jusqu’à 70°C, permet la flottaison de la folle bagasse, dans une cellule, quand l’air s’échappe vers l'atmosphère. Ce concept a été étudié dans une usine a sucre de capacité de 150 t/h avec des résultats très encourageants.

CELDA PARA FLOTACIÓN DE BAGACILLO

Por

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PALABRAS CLAVE: remoción de Bagacillo, flotación.
Resumen

EL INCREMENTO de la preparación de caña para obtener mejores eficiencias de extracción resulta en un significativo incremento del bagacillo en el jugo crudo. En el pasado reciente los tamices rotatorios y los vibratorios han ganado importancia en la remoción de bagacillo. Sin embargo, hay limitaciones dado que los tamices no logran la separación de partículas menores 0.32 mm. El jugo crudo generalmente contiene aire ocluido que es presurizado y disuelto a la salida de las bombas hacia calentadores. El jugo con aire disuelto y calentado a 0°C, cuando se lo libera a la atmósfera en una celda, causa la flotación del bagacillo. Este concepto se ensayó en un ingenio de 150 t/h con resultados muy promisorios.
THE USE OF THE COLOBSERVER® ON LINE COLOUR MEASUREMENT SYSTEM TO AUTOMATE A SUGAR BLENDING PROCESS

By

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KEYWORDS: On-Line, Colour, Measurement, Quality, Colobserver®, Process Optimisation, Blending.

Abstract
Nowadays all sugar mills need to improve their instrumentation and process equipment to keep production costs and energy consumption as low as possible while aiming for a specific quality. The Busco sugar plant has to produce and bag different qualities of sugar as per their customers’ specifications. Thus, Busco asked ITECA to install a Colobserver® and to automatically manage the complete sugar blending process. Different blending schemes were developed in cooperation with the plant to comply with the numerous qualities used by the production. We particularly focused on the automation monitoring and to their associated operating alarms to ensure a perfect operation in a completely automatic mode. All the parameters can be adjusted independently. Today the Colobserver® installed at the Busco plant as well as many other sugar refineries worldwide provides the tailor-made tools that allow refineries to comply with the required quality and to optimise process management. Refineries are also able to track and record their complete production quality, which is very much appreciated by end clients.

Introduction
The Colobserver® is designed to monitor the sugar colour continuously and directly on the process for wet and dry sugar applications.

In the Philippines, Busco Sugar Refinery used to blend its different coloured sugars manually to obtain the requested qualities at the bagging station. It involved frequent laboratory control which could not follow colour drifts in real time to ensure an absolute quality. To increase the constancy of this blending and to automate its process, Busco decided to set up an on-line-colour analyser: the Colobserver®.

The Colobserver® is able to measure sugar colour with great accuracy and, thanks to its integrated PLC, automatically manages the sugar blending process (Gaillac, 2009; Gaillac and Trintignac, 2008; Gaillac and Trintignac, 2009).

Colobserver® description
Colobserver® is sited directly above the sugar to control the total conveyor width. It uses an optical system allowing colour measurement by reflectivity. An important advantage of the use of a video sensor is the possibility to freely adapt various types of lenses according to the size of the region to be measured. Thanks to this technology, the system can easily be adapted on several kinds of conveyor as shown in Figure 1.

Developed with special care to meet the HACCP standard, the stainless steel made device is designed to work on all kinds of conveyor that are found in the sugar industry. It ensures three functions in real-time:
• Monitoring automatically the blending of the colour into the different silos;
• Accurate measurement of the sugar coloration calibrated according to the plant laboratory; and
• Detection and quantification of brown lumps or bad coloration of the sugar

Methodology

The Colobserver® was located on a screw that fed the elevator just before the silo of the bagging station. Its PLC controls the speed of each of the rotary valves which extract the sugar from each of the four silos supplying sugar to the bagging station (see Figure 2).

Different blending schemes were developed in cooperation with the plant to comply with the numerous qualities used by the production:

Bottler – 30 IU max;
Premium – 30–45 IU max; and
Standard – 45–100 IU.
The colour range into each silo is as follows:
W1a & W1b – 7 to 35 IU;
W2 – 60 to 100 IU; and
W3 – 100 to 200 IU.

The sum of all the rotary valve speeds has to be equal to 120 Hz so that there is a constant feed rate to the screw.

As per the requests made by the production manager, the plant laboratory adjusts the colour setpoint on the computer of the Colobserver® to fill the silo with the correct sugar, so that the right quality is sent to the bagging station. The programming logic and data flows for the Colobserver® are described in Figures 3 and 4.

Fig. 3—Program logic for the Colobserver®.
Fig. 4—Information flows for the Colobserver® system.

The Colobserver® considers the height level of sugar in the silos and intelligently proportions sugar to ensure an optimisation of the silo management, so that the obtained colour is always the requested one.

We particularly focused on the automation monitoring and to their associated operating alarms so as to ensure a perfect operation in a completely automatic mode. All the parameters can be adjusted independently.

Conclusion

Today the Colobserver® installed at the Busco plant as well as many other sugar refineries worldwide allows these plants to ensure that a mastered quality product on both wet and dry sugars is delivered to their end customers. They are also able to track and record their complete production quality, which is very much appreciated by end clients.

REFERENCES


L'UTILISATION DU COLOBSERVER® POUR MESURER LA COULEUR EN LIGNE AFIN D'AUTOMATISER LE MELANGE DU SUCRE

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MOTS-CLEFS: En Ligne, Couleur, Mesure, Qualité, Colobserver®, Optimisation du Processus, Melange.

Résumé

Les sucreries désirent améliorer l’équipement et l’instrumentation pour maintenir la consommation d'énergie et les frais de production aussi faibles que possible, tout en visant une qualité spécifique. La sucrerie Busco doit produire différentes qualités de sucre pour leurs clients. Ainsi, Busco a demandé à ITECA d’installer un Colobserver® et de gérer automatiquement le mélange du sucre. Différents schémas de mélange ont été développés en coopération avec l'usine pour produire les nombreuses qualités de sucre demandées. Nous avons particulièrement surveillé l'automatisation et ses alarmes afin d'assurer un fonctionnement parfait dans un mode entièrement automatique. Tous les paramètres peuvent être ajustés de façon indépendante. Aujourd'hui le Colobserver® installé à Busco, et dans d’autres raffineries dans le monde, fournit des outils qui permettent aux raffineries de se conformer à la qualité requise et d'optimiser la gestion des processus. Les raffineries sont également capables de suivre et d’enregistrer la qualité en production, ce qui est très appréciée par les clients.

EL USO DE COLOBSERVER® SISTEMA DE MEDICIÓN DE COLOR EN LÍNEA PARA AUTOMATIZAR UN PROCESO DE MEZCLADO DE AZÚCAR

Por

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PALABRAS CLAVE: En Línea, Color, Medición, Calidad, Colobserver®, Optimización de Proceso, Mezcla.

Resumen

Actualmente todos los ingenios azucareros necesitan mejorar su instrumentación y su equipo de proceso para mantener los costos de producción y el consumo energéticos tan bajos como sea posible, mientras se apunta a una calidad específica. El ingenio Busco debe producir y empaquetar diferentes calidades de azúcar acorde con las especificaciones de los clientes. Por esta razón Busco solicitó a ITECA la instalación de un Colobserver® y el manejo automático del proceso completo de mezclado. Se desarrollaron diferentes esquemas de mezcla en colaboración con la planta para cumplir con las numerosas calidades usadas por la producción. Se enfocó particularmente en el monitoreo automático y en sus alarmas operativas asociadas para asegurar una operación perfecta en un modo completamente automático. Todos los parámetros pueden ajustarse independientemente. Actualmente el Colobserver® instalado en la planta de Busco así como en muchas otras refinerías a nivel mundial suministra las herramientas apropiadas que permiten a las refinerías cumplir con la calidad requerida y para optimizar la gestión de proceso. Las refinerías son también capaces de registrar y seguir completamente su calidad de producción lo cual es muy apreciado por el cliente final.
CONTINUOUS VACUUM PAN – AN ATTEMPT FOR DUAL MASSECUITE BOILINGS WORKING

By

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KEYWORDS: Continuous Vacuum Pan, Heating Surface Volume Ratio, Seed Rate, Ratio Controller, Conductivity Transmitter, Dyno Drive, Automation.

Abstract

The continuous vacuum pan is a boon to the sugar industry by nature of its high heating surface to volume ratio, constant steam demand, more exhaustibility of the massecuite, crystal growth, easy to automate, easy to operate, flexibility in capacity and so on. In Ponni Sugars, one continuous pan of 15 t/h capacity was installed five years ago. Taking advantage of its working pattern, an attempt was made to modify its design slightly to convert the pan from a single massecuite-boiling pan into a double massecuite-boiling pan. The practical experiences are shared in this article.

Introduction

Ponni Sugars (Erode) Limited underwent an expansion from 1250 tcd to 2500 tcd in 1994. This was done by installing limited and essential equipments, keeping the investment cost at minimal levels with no provision for additional built-in-capacity. As a result, Ponni lost the advantage for crushing higher than the rated capacity and could achieve no more than 2250 tcd crushing on an average during any season since the expansion.

The pan section was no exception to this and solids handling with the improved cane variety, and demand for sugar quality with higher crystal size from the market added fuel to the problems. So a decision was made to install a continuous vacuum pan (CVP) of 15 t/h capacity for boiling C massecuite which was subsequently erected and commissioned during 2004.

Continuous pan

The newly erected CVP was operated for C massecuite boiling right from its inception. For two years, the practice was followed. During the operation, it was found that the boiling rate was found so high such that the pan was working only about 10–12 hours a day, the rest of the time being kept idle. Starting and stopping the pan was posing a big problem to the operators. The operational data are enclosed in Appendix 1.

The pan was operated with part automation wherein the molasses feed was added to maintain the consistency of material inside the compartment and the seed was fed at a ratio to the molasses flow rate by using a ratio controller. The automation arrangements are shown in Figure 1.

Modifications made to the CVP

Since this continuous pan was operated in a discontinuous way i.e. the pan was operated for about 10–12 hours per day, several options were considered regarding the working of the pan. These included:

a. to reduce the number of compartments; and
b. to alter the design of the pan to suit working with two massecuites (i.e. B and C massecuites).

The second option was chosen because the existing continuous pan for B massecuite was also getting corroded badly and was incurring huge maintenance expenditure year after year.
Fig. 1—The three main control loops on the CVP prior to the modifications.

Since the design of the new CVP was suitable for the proposed modifications to boil two massecuites, the following modifications were made:

- The CVP was divided lengthwise into two on the vertical plane with respect to the compartment on either side of the top tube plate.
- Necessary changes to the flow path to ensure true plug flow of the massecuite in the different compartments.
- Feed liquor arrangements suitably rearranged to give better mixing of liquor and exhaustion of mother liquor in the CVP.
- Steam distribution divided into two to allow the use of vapour of different pressures for each massecuite.
- The compartment partition plate above the top tube plate was modified to avoid any short-circuiting.
- Plug flow of massecuite was achieved by rearranging the massecuite flow pattern.
- The existing condenser nozzle sizes were increased to suit the increased rate of evaporation.
- Existing partial automation was upgraded to complete automation.

The modifications are illustrated in Figures 2 and 3.

**Operation of the modified CVP**

After the modifications were completed but before the automation was completed, the CVP was recommissioned in 2006. Initially a lot of teething troubles were encountered as complete automation was not available. Since the CVP working efficiency depends wholly on the automation, efforts were concentrated on this aspect. Changes made to the automation system included:

- Existing sensors and transmitters were replaced by reliable and user-friendly equipment.
- VFD arrangements made for pumping B and C footing material.
- Control valves were replaced by proportionate type control valves for On/Off mode.
- Vapour valves were provided with proportionate type control valves.
- Jigger steam arrangements were provided to the bottom of the pan.
- Hot water addition on auto mode provided for further conditioning of molasses.

The logic of the automation is shown in Figure 4.
All the above improvements were made and the pan started working very well on fully automatic mode. The following benefits were noted:

- Throughput from the pan was increased without affecting the efficiency.
- The pan was utilised for the maximum hours of working.
- The flows of massecuites are uniform and centrifugal machines are continuously loaded.
- Improved evaporator performance due to constant steam demand.
- Since start up and stopping operations are avoided, deposits are avoided.
- Automation helps in flexibility to vary throughput according to crushing variations.
- The same logic can work very well for independent massecuite boiling also because of effective steam utilisation.

The data collected during the working of the pan with both massecuites are given in Appendix 2.

**Conclusion**

This novel concept of making the CVP as twin pan was conceived by the author Mr R. Chandamouli and successfully implemented in Ponni Sugars (Erode) Limited. Because of this modification work, not only was the pan utilised to its maximum capacity but also assisted to ease the solids handling on the pan floor. The total cost incurred for the modification works was around Rs. 4.00 lakhs.

It is well known that continuous pans work well only with full automation. Only with full automation did this pan succeed to work well for dual massecuite boiling. The rate of evaporation was found to be constant throughout the operational period. Whenever the pan had to be stopped for more than 4 hours, the contents were emptied, water boiled and again taken into service.
Appendix 1

Performance of C massecuite boiling in continuous vacuum pan before modification

<table>
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<tr>
<th>Date</th>
<th>Cane crushed (t)</th>
<th>BH Molasses Qty/day (t)</th>
<th>C Footing Qty (t)</th>
<th>Crystal size (μm)</th>
<th>C Massecuite Qty (t)</th>
<th>Crystal size (μm)</th>
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Appendix 2

Performance of B massecuite boiling in continuous vacuum pan after modification

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<th>B Footing Qty (t)</th>
<th>Crystal size (μm)</th>
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<td>09/02/08</td>
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<td>137</td>
<td>216</td>
<td>398</td>
<td>330</td>
<td>27</td>
<td>12.19</td>
<td>20.5</td>
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</tbody>
</table>

Performance of C massecuite boiling in continuous vacuum pan after modification

<table>
<thead>
<tr>
<th>Date</th>
<th>Cane crushed (t)</th>
<th>BH Molasses Qty/day (t)</th>
<th>C Footing Qty (t)</th>
<th>Crystal size (μm)</th>
<th>C Massecuite Qty (t)</th>
<th>Crystal size (μm)</th>
<th>CV %</th>
<th>%Cane</th>
<th>Boiling hours</th>
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<tr>
<td>01/02/08</td>
<td>3525</td>
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<tr>
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<td>217</td>
<td>88</td>
<td>120</td>
<td>244</td>
<td>181</td>
<td>18</td>
<td>7.49</td>
<td>20.0</td>
</tr>
</tbody>
</table>

Note: CV data not available before modifications
CUITE CONTINUE—UNE TENTATIVE POUR LE TRAITEMENT DE MASSECUITE DOUBLE

Par

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Résumé
LA CUITE continue apporte beaucoup d’avantages pour l’industrie du sucre; par exemple le fort rapport de sa surface de chauffe au volume, une demande constante de vapeur, un fort épuisement de la mélasse, une bonne croissance cristalline, automatisation et travail faciles, flexibilité dans la capacité, et ainsi de suite. Une cuite continue a été installée à Ponni Sugars avec une capacité de 15 t/h, il y a cinq ans. Une tentative pour modifier sa conception légèrement afin de permettre le traitement de massecuite double a été faite. Les expériences pratiques sont partagées dans cet article.

TACHO CONTINUO—UN INTENTO PARA COCIMIENTO DUAL DE MASAS

Por

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PALABRAS CLAVE: Tacho Continuo, Razón Área/Volumen, Tasa de Semillamiento, Controlador Proporcional, Transmisor de Conductividad, Dyno Drive, Automatización.

Resumen
EL TACHO continuo es importante para la industria azucarera en razón de su alta relación de área de calentamiento a volumen, demanda constante de vapor, mayor agotabilidad de las masas, crecimiento de cristal, facilidad de automatización y operación, flexibilidad en capacidad y así sucesivamente En Ponni Sugars, un tacho continuo de 15 t/h de capacidad fue instalado hace 5 años. Aprovechando su esquema de funcionamiento, se intentó modificar ligeramente su diseño para convertirlo en un tacho para cocimiento de doble masa. En este artículo se comparten las experiencias.
ADVANCED COOLING TECHNOLOGY HELPS INGENIO TRES VALLES INCREASE CAPACITY

By

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²Ventura Process Equipment Company
neville.jordison@solexthermal.com

KEYWORDS: Sugar Dryer, Sugar Cooler, Refined Sugar, Indirect Plate Cooler, Mass Flow.

Abstract

In 2006, Ingenio Tres Valles S.A. wanted to increase their plant production capacity and considered various ways in which this could be accomplished. Increasing the capacity in the drying and cooling sections was one of the requirements to ensure a top quality product. The challenges they faced were to select efficient technologies that would fit in the available space, utilise existing equipment where possible and offer the most cost effective solution. To increase the drying capacity of refined sugar, the decision was made to convert the existing rotary drum cooler to a rotary dryer. The next step was to add a stand-alone cooler. Tres Valles evaluated several options for the cooler; a fluid bed cooler, a rotary cooler and an indirect plate cooler. The indirect plate cooler operates on the principle of mass flow of sugar through a vertical bank of water cooled plates. After a thorough evaluation, Tres Valles selected an indirect plate cooler from Solex Thermal Science since the vertical configuration and small cross section fit easily into their existing facility. The indirect plate cooler also offered the most cost effective and energy efficient solution. The equipment was installed and commissioned in January 2008 in time for the seasonal operating campaign. The new drying/cooling configuration is now in the second operating campaign and has successfully played a role in increasing sugar production capacity at Ingenio Tres Valles. Quality objectives have been fully achieved and the equipment has met and exceeded the energy efficiency targets.

Introduction

The Ingenio Tres Valles S.A. plant in Veracruz, Mexico was operating with the conventional arrangement of two rotary dryer/cooler drums, each operating at the maximum capacity of 35 t/h. Tres Valles set plant objectives to increase capacity to a production rate of 75 t/h and improve product quality. From a quality perspective, they wanted to reduce ‘lumping’ of the product that was occurring due to moisture and temperature upsets which, in the 2006/2007 operating campaign, resulted in six quality claims against them from customers.

A technical and economic analysis was carried out to determine the best way to increase drying and cooling capacity as well as improve the quality and consistency of the product at the desired increased production rates.

With the deregulation of the sugar industry in Mexico, quality is becoming an increasingly important consideration with customers. Customers may require final product quality to be certified according to (among others):

- ISO 9001–2000;
- Hazard Analysis and Critical Control Point (HACCP);

...
• FDA (Federal Drug Administration);
• Kosher.

With this in mind, Ingenio Tres Valles required their production process to be able to meet these standards as this would help to differentiate them in the Mexican sugar market. In the short term, it was planned to ship some product in 1500 kg super sacks where there is an increased tendency for caking if the sugar is not fully dried and cooled.

**Tendency for caking**

The mechanism for sugar forming a ‘cake’ or ‘lump’ is caused by moisture migration through the sugar as illustrated in Figure 1. The moisture migration causes a ‘cement’ to form between adjacent crystals where they touch, forming a weak bond which leads to ‘lumping’. Moisture migration through the sugar is caused by the temperature gradient between the sugar and the ambient conditions. These conditions exist when sugar is stored or put in bags at too high a temperature. The requirement is to store the sugar close to ambient temperatures. Typically sugar is cooled to a temperature within 5ºC of ambient which minimises the risk of agglomeration.

![Figure 1—Micro crystal growth leads to caking.](image)

**Evaluation of available technologies**

The starting point of the study was to consider the possible alternatives. Following the study, three possible solutions were identified:

• Adding another rotary dryer;
• Changing to a fluidised bed cooler; and
• Converting the existing rotary cooler to a dryer and installing an indirect plate cooler to meet the cooling duty.

The first two options (rotary dryer and fluidised bed cooler) used equipment well known to the sugar industry in Mexico. The third option, using an indirect plate cooler, was not familiar to the Tres Valles engineers and had not been installed in any of the sugar factories in Mexico, although the technology had been extensively used in sugar factories in Europe.

**Description of the indirect plate cooler technology**

Plate heat exchanger technology has been applied to the bulk solids industry for approximately 20 years. The technology was first introduced in the fertiliser industry to cool bulk fertiliser and was quickly introduced to other bulk solid industries. Plate coolers have been used to cool crystalline sugar (beet and cane) for 10 years.

The idea behind the technology is simple: the bulk solid, in this case sugar crystals, flows slowly by gravity between water cooled plates as illustrated in Figure 2. The sugar crystals are cooled by conduction.
Fig. 2—Sugar crystals flow slowly between water cooled plates.

The heat exchanger plates are stainless steel and are of fully welded construction, with no gaskets; this design ensures very high mechanical integrity.

Water flows through the plates in counter-current flow with respect to the product flow, achieving high thermal efficiency. The plates are installed as a bank in a stainless steel casing.

**Uniform velocity**

The second requirement of an indirect plate cooler is that the sugar must flow at the same velocity over the full cross section of the heat exchanger to ensure an equal residence time which will result in uniform cooling as illustrated in Figure 3.

Uniform flow is achieved with a vibrating feeder discharge comprising overlapping shallow angled louvres. Product flow is proportional to the frequency of vibration and, when the feeder tray is stationary, there is no product flow due to the angle of repose of the sugar.

Fig. 3—Illustration of uniform velocity with full cross section vibrating feeder.
The advantages of indirect cooling

Indirect cooling with water results in several significant cost and quality advantages compared with direct cooling with air-sugar contact:

Air coolers require a large quantity of air for the cooling duty. This is inefficient, requiring a chiller and reheater, large fans and a dust collection system to prevent emissions to the atmosphere. This additional equipment adds to both installed capital and operating costs. In comparison an indirect plate cooler operates on a chilled water circuit.

- Direct cooling with air introduces the risk of contamination of the sugar crystals if there are micro-organisms present in the air.
- The slow gravity flow of the sugar through the indirect plate cooler is ‘gentle’ compared to a fluidised bed or rotary drum cooler. This gentle handling reduces degradation and breakage of the sugar crystals.
- The floor space required for the indirect plate cooler is small since cooling occurs in the vertical direction whereas, in a fluidised bed or rotary drum cooler, the product flow is horizontal, thus requiring a much larger floor space. This is a particular advantage in retrofit projects where floor space is usually very limited.

Water chillers use approximately 40% less energy than air chillers for the same heat load. This is explained by the fact that with an air chiller, the air must first be cooled to supersaturation, typically 10°C and 100% relative humidity and then reheated above the saturation point, typically 15°C and 70% relative humidity.

This requires energy to condense the moisture present in the air, plus the energy required for the reheat. With a chilled water system the only energy requirement is the sensible heat load to chill the water.

Technical and economic evaluation of alternative technologies

A comparison was made of the available technologies and summarised in Table 1.

Table 1—Technology and economic comparison.

<table>
<thead>
<tr>
<th>Factor/Technology</th>
<th>Rotary dryer/cooler</th>
<th>Fluidised bed dryer/cooler</th>
<th>Indirect plate cooler</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependency on air for cooling</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Use of peripheral equipment</td>
<td>Yes</td>
<td>Yes</td>
<td>Small</td>
</tr>
<tr>
<td>High level of automation</td>
<td>No</td>
<td>Complex</td>
<td>No</td>
</tr>
<tr>
<td>Installation</td>
<td>Simple</td>
<td>Complex</td>
<td>Simple</td>
</tr>
<tr>
<td>Operating Simplicity</td>
<td>Simple</td>
<td>Complex</td>
<td>Simple</td>
</tr>
</tbody>
</table>

The energy consumption for each option was also evaluated. The results are shown in Table 2. The power consumptions quoted for the rotary and fluidised bed cooler are for the fans and drives for the drum. Table 2 does not include the power requirement for the chillers in either the rotary dryer, fluidised bed or the indirect plate cooler.

Table 2—Power consumption comparison.

<table>
<thead>
<tr>
<th>Capacity/ Technology</th>
<th>Rotary dryer/ cooler</th>
<th>Fluidised bed</th>
<th>Indirect plate cooler</th>
</tr>
</thead>
<tbody>
<tr>
<td>45.5 t/h</td>
<td>150 kW</td>
<td>140 kW</td>
<td>13 kW</td>
</tr>
<tr>
<td>91 t/h</td>
<td>300 kW</td>
<td>277 kW</td>
<td>54 kW</td>
</tr>
</tbody>
</table>

Reference plants

The next step in the evaluation for the Tres Valles engineers was to visit reference plants in Europe where there were a number of plants using the indirect plate cooler technology. The objective of the visit was to see the installations and discuss operating experience, equipment reliability and maintenance issues with the plant technical and operating personnel. Table 3 lists the plants visited.
Table 3—Reference plants.

<table>
<thead>
<tr>
<th>Plant</th>
<th>Product</th>
<th>Country</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toury</td>
<td>Refined sugar</td>
<td>France</td>
<td>Indirect plate cooler</td>
</tr>
<tr>
<td>Nordstemmen</td>
<td>Refined sugar</td>
<td>Germany</td>
<td>Fluidised bed</td>
</tr>
<tr>
<td>RAR</td>
<td>Refined sugar</td>
<td>Portugal</td>
<td>Indirect plate cooler</td>
</tr>
</tbody>
</table>

Results of technology evaluation

Each of the three methods of cooling was considered technically viable and mechanically reliable. After careful evaluation, the choice between the different technologies was made on two principal criteria:

- Ease of installation
- Energy savings

On this basis, the indirect plate cooling technology was selected for the plant upgrade. Tres Valles plant engineers chose the heat exchanger technology offered by Solex Thermal Science.

System design and process control

Tres Valles specified the following design conditions for the indirect plate cooler:

Capacity: 80 t/h
Product in: 60ºC
Product out: 35ºC
Water temperature in: 25ºC (from chiller)

To meet this duty, Solex configured the indirect plate cooler as a double bank design, with the water flow in series. A simple process flowsheet of the system is shown in Figure 5.

Fig. 5—Tres Valles process flowsheet.
Commissioning

Commissioning took place in November 2007 and the cooler was quickly on stream, meeting the required cooling performance. The Solex commissioning team was on site to assist with set up and calibration of the equipment and to observe the first few days of operation. In addition, on-site training was provided to the Tres Valles operations team.

Performance review 2007/2008 operating campaign

After operating the plate cooler through the 2007/2008 operating campaign, the following observations were made:

- Tres Valles was able to consistently maintain the product temperature to storage at the target temperature of 35°C
- The claims associated with lumping decreased from six in the 06/07 campaign to two in the 07/08 campaign. It has been identified that the two claims in the 07/08 campaign were the result of failures with the chilled water supply where they were unable to maintain the required cooling water temperature.
- The plant was also able to achieve the goal of increasing production capacity and did so in the 07/08 campaign by 20 000 tonnes from the previous campaign.

Conclusions

Ingenio Tres Valles needed to increase their sugar crystal cooling capacity to meet higher production targets and improve quality. They investigated alternative technologies including an additional rotary cooler, a fluidised bed and an indirect plate cooler for this duty. The indirect plate cooler had not previously been used in the Mexican sugar industry, so more in-depth study was required to understand both the advantages and disadvantages of the technology. They needed to ensure that this type of equipment could achieve reliable operation with a high on-stream factor and low maintenance cost.

Following the evaluation of the three possible technologies, the indirect plate cooler was selected since it most closely met the plant objectives.

The equipment was installed in the fall of 2007 in time for the 2007/2008 operating campaign. Operating experience through the first campaign proved the equipment fully met the objectives of the project. The equipment has now operated through the second season 2008/2009 and has again proven to achieve effective cooling and reliable operation.

Acknowledgements

We would like to acknowledge the support of the technical staff at Ingenio Tres Valles, it would have been impossible to prepare this poster without their help. Special thanks to Ingeniero Guillermo Mendoza Castillo, who was in charge of the project and the performance evaluation.

Une technologie avancée de refroidissement contribue à l’augmentation de capacité à Ingenio Tres Valles

Par

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MOTS-CLEFS : Sécheur, Refroidisseur, Sucre Raffiné, Refroidisseur a Plaques, Bilan Massique.

Résumé

En 2006, Ingenio Tres Valles S.A. voulait augmenter la capacité de sa production et a considéré différentes possibilités. On a trouvé nécessaire d’augmenter la capacité dans les sections de séchage et de refroidissement, afin de garantir un produit de qualité supérieure. Les problèmes rencontrés
ont été la sélection de technologies efficaces pour l’espace disponible, l’utilisation de l’équipement existant dans la mesure du possible et une solution efficace au point de vue du coût. Pour augmenter la capacité de séchage du sucre raffiné, on a converti le refroidisseur a tambour rotatif en sécheur rotatif. L’étape suivante a été l’addition d’un refroidisseur autonome. Tres Valles a évalué plusieurs options pour le refroidisseur; un refroidisseur a lit fluidisé, un refroidisseur rotatif et un refroidisseur a plaques. Dans le refroidisseur a plaques un débit massique de sucre passe a travers une bande verticale des plaques refroidies a l'eau froide. Après une évaluation approfondie, Tres Valles a sélectionné un refroidisseur a plaques de Solex Thermal Science qui s'intègre facilement dans leurs installations existantes. Le refroidisseur a plaques offre un coût et une demande d’énergie économiques. L'équipement a été installé et mis en service en janvier 2008, a temps pour la campagne. La nouvelle configuration de refroidissement/séchage est maintenant dans sa deuxième campagne d'exploitation et a permit une augmentation de la capacité de production du sucre à Ingenio Tres Valles. La qualité a été atteinte; l'équipement a atteint, et même dépassé, les objectifs d'efficacité énergétique.

TECNOLOGÍA DE ENFRIAMIENTO AVANZADA AYUDA AL INGENIO TRES VALLES A INCREMENTAR SU CAPACIDAD

Por

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PALABRAS CLAVE: Secadora de Azúcar, Enfriadora de Azúcar, Azúcar Raffinado, Enfriador Indirecto de Placa, Flujo Másico.

Resumen

EN EL 2006, Ingenio Tres Valles S.A. deseó incrementar su capacidad de producción y consideró varias rutas para lograrlo. El incremento de la capacidad en secado y enfriamiento de azúcar fue uno de los requerimientos para asegurar u producto de alta calidad. Los retos que ellos enfrentaron fueron la selección de tecnologías eficientes que pudieran acomodarse en el espacio disponible, el uso de equipo existente donde fuera posible y ofrecer la solución más costo-efectiva. Para incrementar la capacidad de secado de azúcar refinado, la decisión fue convertir el tambor rotatorio de enfriamiento existente en una secadora rotatoria. El siguiente paso fué adicionar una enfriadora independiente. Tres Valles evaluó varias opciones para la enfriadora: una de lecho fluidizado, una rotatoria, y una enfriadora indirecta de placas. La enfriadora indirecta de placas opera bajo el principio de flujo másico de azucar a través de un banco vertical de placas enfriadas por agua. Después de una evaluación exhaustiva, Tres Valles seleccionó una enfriadora indirecta de placas de Solex Thermal Science dado que la configuración vertical y la pequeña sección transversal se acomodaban al espacio disponible. Este equipo también ofrecía la solución más costo-efectiva y la mas eficiente energéticamente. El equipo fue instalado y puesto en marcha en Enero 2008 a punto para la zafra. La nueva configuración de secado/enfriado se encuentra ahora en su segunda zafra y ha desempeñado exitosamente un rol en el incremento de la capacidad de producción de azúcar en el Ingenio Tres Valles. Los objetivos de calidad han sido completamente alcanzados y el equipo ha cumplido y superado los objetivos de eficiencia energética.
A VEGETABLE CLARIFYING AGENT
FOR CANE JUICE CLARIFICATION

By

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KEYWORDS: Clarification, Flocculant, Settling, Mud, Clarity, Hibiscus lunarifolius.

Abstract
There is a continuous quest for biologically-derived flocculants to avoid chemically manufactured flocculants for cane juice clarification. Attempts were made to investigate vegetable-derived clarifying agents which are substitutes for the imported flocculants and cheaper. A comparative study was made with chemical flocculant used normally in sugar factories on settling characteristics, juice clarity and the compactness of mud. It was observed that the use of 3 ppm of Hibiscus lunarifolius extract provides a similar performance to 2 ppm of chemical flocculant. This plant extract has a peculiar property which helps in reducing the unwanted colours in the juice. The plant extract assumes a significant role as an alternative for chemical settling agents. The plant has wider adoptability in terms of its agro-climatic requirements and can be grown as a sole crop or as an intercrop in sugarcane having wide or paired row planting system. Thus an environmentally friendly plant extract is made useful to replace chemicals in the sugar industry.

Introduction
Most of the sugar mills are importing expensive settling aids for settling mud and to improve the clarity of the clear juice. The settling agents are added to the heated juice before entering the clarifiers.

To avoid these costly chemicals, it is preferable to introduce alternatives which can be environmentally friendly, less expensive and easily adopted.

In the manufacture of Khandasari and Gur sugars, the cane juice is clarified with plant extracts viz. 1. Hibiscus ficulneus (Deola), 2. Hibiscus esculentus (Bhindi), 3. Cadia celsina (Sukhlai), 4. Bombax malabarum (Semal Bark), 5. Grewia asiatica (Falsa), 6. Arachis hypogaea (Ground Nut), 7. Recinus communis (Castor Seed), 8. Aloe vera (Indian Aloe), 9. Moringa oleifera and Cordia myxa etc.

Based on these, it was postulated that the extract from such plants could be used in the process of clarification of cane juice for better flocculation and faster settling. In this paper, the details of the experiments conducted with Hibiscus lunarifolius and the results obtained are discussed.

Details of the plant
Hibiscus lunarifolius belongs to the Malvaceae family of the plant kingdom. It is herbaceous and 2–3 metres high. Physically, it resembles the Ladies Finger plant with the main difference being the length of the fruit which is 1/5 of the real Ladies Finger. The seeds are brown and minutely tubercled. The name of the plant in English is Van kapas.

The Van kapas plant is cultivated in the same way as Ladies Finger using seeds and can also be propagated by stem cuttings. Within 30 days after sowing, the plant will bear flowers and fruits. The leaves contain a sticky substance called mucilage which contains an albumin-like substance responsible for coagulating and bleaching characteristics.
The ideal time for picking the leaves to obtain the extract which can be used as a flocculant for cane juice clarification is before 30 days. Leaves will be broader before bearing of fruit bodies. If entire leaves are plucked, secondary leaves will develop within a few days. The plant can be irrigated once a week. It is a wild variety and can be grown in red and loamy or black and black loamy soil. Extracts can be obtained from the entire plant. The approximate crop duration is 3–4 months. The Van kapas plant can be found in tropical Africa, Australia, Sri Lanka and India.

### Experimental procedure

#### Extraction of plant material

Matured leaves of the plant were collected and washed with water. The leaves were soaked in water and squeezed to obtain the extract. The extract was then filtered through a cloth.

#### Preparation of solution

A 0.05% solution of *Hibiscus lunarifolius* extract was prepared by taking 0.5 g of the extract in a 100 mL volumetric flask. About 80 mL of distilled water was added. The flask was stopped and shaken well to dissolve the extract. The volume was then made to 100 mL using distilled water and further diluted ten times with distilled water to give 0.05% solution.

#### Use of the extract for clarification

Raw juice was obtained from processing sugarcane in a laboratory crusher. The juice was analysed for brix, pol, purity and pH and then heated to 70°C and limed to pH 7.2 and then heated to 100°C.

A series of 6 × 1 L measuring jars was prepared by adding the *Hibiscus lunarifolius* at 1 ppm, 2 ppm, 3 ppm, 4 ppm and 5 ppm, respectively. The sixth jar was empty as a blank.

One litre of the boiled juice was added to each jar. Each jar was stirred well and the contents allowed to settle. The settling rate was observed at regular intervals and recorded using a stop watch. The clarity of the clear supernatant liquid from all the measuring jars was measured using the Kopke turbidity meter (Meade and Chen, 1982) and recorded in Table 1.

#### Table 1—Use of *Hibiscus lunarifolius* extract in raw juice clarification.

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Blank</th>
<th>1 ppm</th>
<th>2 ppm</th>
<th>3 ppm</th>
<th>4 ppm</th>
<th>5 ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>3</td>
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<td>0.08</td>
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<td>370</td>
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<tr>
<td>Colour, IU</td>
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<td>14500</td>
<td>12000</td>
<td>11000</td>
<td>14000</td>
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</table>

In a similar way experiments were conducted with treated juice going to clarifier and the results recorded in Table 2.
Table 2—Use of the *Hibiscus lunarifolius* extract with sulfited juice.

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Blank</th>
<th>1 ppm</th>
<th>2 ppm</th>
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<tr>
<td>Colour, IU</td>
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<td>14 400</td>
<td>13 000</td>
<td>11 000</td>
<td>12 800</td>
<td>14 000</td>
</tr>
</tbody>
</table>

Comparison of the extract with chemical flocculant

A 0.05% of solution of the chemical flocculant Magnafloc LT27, having a molecular weight of about 18 million, was prepared in a similar manner to the plant extract.

Tests on raw juice using chemical flocculant were conducted using the same method that was used for the plant extract so that the two could be compared. For these tests the settling rates were recorded in Table 3.

Table 3—Use of the LT27 with raw juice clarification.

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Blank</th>
<th>1 ppm</th>
<th>2 ppm</th>
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<td>110</td>
<td>290</td>
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<td>140</td>
<td>110</td>
</tr>
<tr>
<td>Colour, IU</td>
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<td>14 200</td>
<td>11 000</td>
<td>12 000</td>
<td>14 000</td>
<td>14 000</td>
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</tbody>
</table>

Comparative study

The juice obtained from the laboratory crusher was analysed for brix, pol, purity and pH. The juice was heated to 70°C. It was limed and the pH was adjusted to 7.2 by using sulfur dioxide gas and, to complete the reaction, the treated juice was heated to 100°C.

Three 1 L measuring jars were used. The first one was kept as a blank. In the second and third jars, 3 ppm of extract and 2 ppm of chemical flocculent respectively were added. The boiled
juice was poured into each of the three measuring jars and the volume was adjusted to 1 L mark. The contents of the measuring jars were stirred and the precipitate was allowed to settle. The data are recorded in Table 4.

Table 4—Comparative study of the effect of *Hibiscus lunarifolius* extract with chemical flocculant with raw juice clarification.

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Mud volume (mL)</th>
<th>Blank</th>
<th>3 ppm extract</th>
<th>2 ppm flocculant</th>
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<td>Bx</td>
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<tr>
<td>Colour, IU</td>
<td>18 000</td>
<td>11 400</td>
<td>12 000</td>
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</tbody>
</table>

Observations and discussion

From the analytical data, the optimum dosage of *Hibiscus lunarifolius* extract and chemical flocculant were found to be 3 ppm and 2 ppm respectively from Tables 1, 2 and 3. The results showed that the addition of *Hibiscus lunarifolius* resulted in faster mud settling rates and the mud volume was more or less equal in the case of chemical flocculant and the blank. The clarity analysis revealed that the supernatant juice obtained by the addition of *Hibiscus lunarifolius* extract was found to be similar to the juice obtained by the addition of LT27. The colour of clear juice obtained using LT27 at 2 ppm level was 11 000 IU, the same level as that obtained with the plant extract at 3 ppm. Due to the higher expenditure the colour analysis was not continued.

Table 4 reveals that the plant extract at 3 ppm gave a similar mud volume compared to the chemical flocculant at 2 ppm. Other parameters like brix, purity rise, pH, clarity and colour of the juice also showed similar results with these treatments.

Experiments are under way to analyse the constituents of *Hibiscus lunarifolius* extract that may be responsible for its flocculating characteristics and bleaching action. The effect of *Hibiscus lunarifolius* extract with the cane juice at different stages of processing will also be studied. Attempts are also made to crystallise *Hibiscus lunarifolius* extract to make it suitable for storage and marketing.

Conclusion

The comparative results of *Hibiscus lunarifolius* plant extract and the chemical flocculant reveal that 2 ppm of chemical agent produced similar results as 3 ppm of plant extract for settling of the mud in the juice. In addition, the formation of the floc is quicker and the flocs are larger with *Hibiscus lunarifolius*.

In view of these benefits, the extract assumes a significant role and is an ideal substitute for the traditional settling aid. The plant has a wide adaptability in terms of its agro-climatic
requirements and can be grown as a sole crop or as an intercrop in sugarcane having wide or paired row planting system. Even though the plant belongs to the same family of Malvaceae, unlike Ladies finger, it is not widely used. Rather, it is considered ornamental.

The plant extract is environmentally friendly. The cultivation of the plant may provide for an extra income for the farmers.

Acknowledgement

The authors are thankful to the Chairman of KSI and Cane Commissioner for Cane Development and Director of Sugar, Government of Karnataka, Director, Karnataka Sugar Institute, Belgaum.

REFERENCE

UN AGENTE CLARIFICANTE VEGETAL PARA
CLARIFICACIÓN DE JUGO DE CAÑA

Por

P. THANGAMUTHU and R.B.KHANDAGAVE
Karnataka Sugar Institute, Belgaum, India
thangamuthu_p@yahoo.co.in   drrbk1232@yahoo.com

PALABRAS CLAVE: Clarificación, Floculante, Sedimentación, Lodo, Turbiedad, *Hibiscus lunarifolius*.

Resumen

Hay una continua búsqueda de floculantes biológicamente derivados para eliminar los obtenidos químicamente, usados en la clarificación de jugos de caña. Se han hecho esfuerzos para investigar agentes clarificantes de origen vegetal como sustitutos de floculantes importados y más baratos que estos. Se hizo un estudio comparativo con floculantes comerciales en cuanto a características de sedimentación, turbiedad y densidad de lodos. Se observó que el uso de 3 ppm de un extracto de *Hibiscus lunarifolius* proporcionó un desempeño similar a 2 ppm de un floculante químico. Este extracto tiene una propiedad peculiar que ayuda en la reducción de colores no deseados en el jugo. El extracto de la planta juega un rol significativo como una alternativa a los agentes sedimentadores químicos. La planta tiene una amplia adaptabilidad en términos de sus requerimientos agroclimáticos y puede cultivarse como único producto o como un cultivo asociado con la caña en un sistema de surco alternos. De esta manera un extracto de planta, ambientalmente amigable, es planteado como útil en el reemplazo de químicos en la industria azucarera.
REPORT ON THE SECOND ISSCT MANAGEMENT WORKSHOP, MAY 2008

By

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Abstract

THE SECOND ISSCT Management Workshop held in Townsville, Australia in May 2008 attracted 41 delegates from 10 countries. The Management Commission and its workshops aim to enlarge the role of senior industry managers in the ISSCT, particularly to integrate management aspects into research and technological initiatives. The workshop format comprised presentations around a particular theme followed by interactive discussion where problems were contextualised and pragmatic solutions sought. A forum for CEOs and senior staff of research organisations followed the Workshop. Overall, the workshop was a success with helpful outcomes emanating from the four sessions: renewable energy, supply chains, research and development (R&D), and special projects. Suggested topics for future workshops include: (1) the R&D fraternity should identify three or four R&D priorities for the next 10 years; (2) experience and business strategies of large sugarcane-related companies should continue; (3) technology transfer and extension needs to be revisited; (4) human resource issues related to attracting and retaining talent in the organisation and change management tools; (5) investigating the use of ‘economic/commercial’ skills in the R&D context; (6) cane-payment approaches applicable to the renewable energy paradigm; and (7) environmental concerns.

Introduction

The second ISSCT Management Workshop held in Townsville, Australia in May 2008 attracted 41 delegates from 10 countries. The Management Commission and its workshops aim to enlarge the role of senior industry managers in the ISSCT, particularly to integrate management aspects into research and technological initiatives. In this regard, the workshop format of the first ISSCT Management Workshop held in Durban, South Africa in July 2006 was considered by the delegates then as appropriate, i.e. presentations around a particular theme followed by interactive discussion where problems were contextualised and pragmatic solutions sought. A similar format was adopted in Townsville where full scientific papers were not requested from presenters, only a PowerPoint presentation, the focus of the workshop being the interactive discussion. Although some delegates at the Durban Workshop suggested the inclusion of breakaway groups to address special interests with a plenary report back, this was not adopted at the Townsville Workshop because the plenary was of a size that (1) facilitated inclusive discussion and (2) diverse expertise and experience facilitated ‘fresh’ approaches to problem solving.
Following this workshop, Eoin Wallis (Chief Executive Officer, BSES Limited, Australia) coordinated a forum for CEOs and senior staff of research organisations to brainstorm common issues.

This paper gives a précis of the proceedings and the main lessons learned from the perspectives of both the organising committee (the authors of this paper) and the delegates (from a questionnaire).

**Field Trip**

The field trip involved a bus tour to the Burdekin District, 80 km south of Townsville, where the first stop was with the HCL Harvesting Group (120 000 t cane). Insights were shared on the group’s organisational structure and workforce complement, its equipment and operations, and its farming systems, including controlled traffic using GPS guidance, minimum tillage and break crops. A cane-planting operation was observed before leaving for BSES Burdekin near Ayr, where cane variety trials were explained and innovative cane-planting practices demonstrated. This was followed by a short visit to an independent grower’s farm where the challenges of cane farming were frankly explained in the context of aspiring to Australia’s acclaimed Sugar Yield Decline Joint Venture Program.

The delegation then returned to BSES Burdekin for lunch, followed by a visit to Pioneer Mill, which is owned by CSR (collectively across its seven mills, CSR produces approximately 40% of Australia’s sugar). The focus of the mill tour was its cogeneration capability (68 MW with 50 MW export capacity) and bagasse-handling facilities (> 110 000 t), as additional bagasse is sourced from nearby mills.

There was general consensus among the delegates that the field trip was appropriate despite the diverse backgrounds of delegates; i.e. the mixture of growing and milling, research activities and practical operations. Some delegates indicated that more attention needed to be given to areas such as cane breeding, farm related research, farm equipment suppliers and milling.

Most delegates appreciated the frank discussions regarding agronomic challenges, the insights into grower/miller relations, the hospitality of the hosts, and the expert commentary on the bus.

**Workshop Session 1—Renewable Energy**

Three presentations were made: ‘Dombe ethanol and cogeneration project in Mozambique’ by Graeme Bullock (Adjunct Professor and Consultant to Principle Energy, Australia), ‘The EID Parry experience with renewable energy’ by Ramesh Ponnuswami (Vice President: Refinery, EID Parry Ltd, India), and ‘Next generation technologies towards a sustainable biofuels future’ by Emile Van Zyl (Chair of Energy Research: Biofuels and Alternative Clean Fuels, South Africa). Questions raised in the subsequent discussion were:

1. What are the drivers of global renewable energy and why?
2. What are the renewable energy options from sugarcane, current and future, and what is their technology status?
3. Where does sugarcane fit into global renewable energy planning and how can this status be improved?
4. What fundamental changes are needed for sugarcane operations to sustainably embrace renewable energy?
5. What are some of the ‘gaps’ or ‘short comings’ in fast-tracking implementation programs?
6. What options are available to narrow these ‘gaps’ and ‘short comings’?, and
7. How can the change process or paradigm shift be fast tracked?
Some of the salient points emanating from the discussion and questionnaires received were:

- There are four fundamental global drivers of renewable energy that are not specific to sugarcane: (1) global warming and environmental factors; (2) national energy security in terms of a supply and demand imbalance; (3) national balance of payment concerns where the importation of energy is often a nation’s single biggest cost; and (4) job creation and socio-economic factors.

- Simplistically, ‘clean’ sugarcane currently delivered to a mill comprises water, fibre, sucrose and dissolved solids including sugars other than sucrose. Inherent energy sources are approximately 30% from sucrose, 13% from dissolved solids and 57% from fibre. Converting the sucrose and other dissolved sugars into energy is well established through fermentation and distillation. Efficient and economic conversion of fibre into energy remains a challenge. Research around the world is currently focused in the following ‘second generation’ energy from fibre areas: (1) combined cycle cogeneration to produce electricity; (2) gasification to produce multiple products in a bio-refinery; (3) pyrolysis to produce a crude bio-oil; and (4) hydrolysing the cellulose, hemi-cellulose and lignin into their constituent sugars for fermentation into ethanol (lignocellulosic ethanol). Commercial viability and role-out of some technologies are expected within 3–5 years.

- In terms of existing ‘first generation’ renewable energy harvests from sugarcane, cogeneration (the combustion of bagasse to produce high-pressure steam that in turn drives turbo-alternators to produce electricity) is the most prevalent; the production of ethanol from sugar streams is second. Generally, the viability of cogeneration depends on either an inherently high local electricity price, or a premium paid for its ‘renewable’ attributes that is facilitated through legislation.

- The ‘greenfields’ Dombe ethanol and cogeneration plant currently being established in Mozambique by Principle Energy demonstrates that the business model: (1) is economically viable and internationally cost competitive; (2) provides significant ‘spin-offs’, such as job creation and infrastructure development, benefit neighbouring communities; and (3) provides balance of payment advantages to the Mozambique nation as a whole.

- The success of EID Parry in India as a company is based on the following principles: (1) ensuring international competitiveness; (2) continuous improvement and innovation; (3) building a strong home base; (4) staying informed with best practice and latest trends; and (5) networking and collaborating in the global arena. Investing in the renewable energy sector is considered strategic. Their inventiveness in maintaining a credible cane supply from approximately 100 000 small-scale farmers in a difficult business environment is remarkable.

- It was affirmed that sugarcane is likely to be the commercial energy crop of the world in the not too distant future, but its momentum to-date has been constrained by: (1) the complex nature of the value chain and the quantum of change required; i.e. linking agriculture to agri-processors to petro-chemical companies or electricity distributors and to the consumer or public at large; (2) inappropriate government legislation and ill-informed politicians and government officials in terms of reviewing legislation; (3) indecision or ignorance on the part of sugarcane growers and millers in terms of which technology to invest their capital; and (4) unforeseen risks associated with new technology and immature markets. Sugar industries around the world should consider embarking on a marketing campaign to inform all stakeholders of renewable energy advantages of sugarcane.
• Little focus has been given to researching appropriate agronomic practices associated with ‘energy’ cane, their linkages with the processing facilities and associated institutional frameworks. For example, what are the soil-health impacts of delivering most of the biomass to the mill, how will the high bulk/density biomass be economically transported to the mill, how will the mill manage the initial volumes of biomass without compromising other products, and how will growers be paid for biomass?

Workshop Session 2 – Supply Chains

Five presentations were made: ‘Integrating the Mauritian supply chain’ by Kassiap Deepchand (MSIRI, Mauritius), ‘Legislative versus contractual miller/grower relationships in Australia’ by John Pollock (Mackay Sugar, Australia), ‘Harvesting and transport logistics in Thailand’ by Kanchana Sethanan (Khon Kaen University, Thailand), ‘Transport scheduling and related issues in South Africa’ by Peter Lyne (SASRI, South Africa), and ‘An holistic approach to new farming systems in Australia’ by Alan Garside (BSES, Australia). Questions raised in the subsequent discussion were:

(1) What is the role of government policy within sugarcane supply chains?
(2) How can incentives and relationships be aligned in the absence of legislation?
(3) What are the relative roles of legislation, contracts, trust and integration in terms of improving supply-chain efficiencies?
(4) How will renewable energy and other products impact supply-chain efficiencies?
(5) How can harvesting seasons be extended for the benefit of all stakeholders?, and
(6) How can incentives be given to sugarcane growers to deliver feedstock that optimises downstream value-adding activities?

Salient points emanating from the discussion and questionnaires received were:

The Mauritian experience demonstrates that a crisis is an excellent change agent! A 36% sugar price reduction in the EU was the catalyst to re-engineer the Mauritian sugar industry where all stakeholders were forced to make compromises in order to survive!

A re-engineering of the supply chain in the quest for efficiencies and optimisation requires a good understanding of the supply chain and its interrelationships. Effective logistics planning necessitates that ALL supply-chain components are integrated effectively.

The sugarcane supply chain was defined by the workshop as ‘on-farm sugarcane production, sugarcane harvesting and transport to the mill and sugarcane processing at the factory’. Most sugarcane supply chains are fragmented in terms of different segments having different decision-making authorities, causing a breakdown in communication among stakeholders. This fosters misunderstandings about common problems, resulting in little or no commitment to jointly address problems, which ultimately manifests itself in high costs and an inefficient supply chain. The fundamental element of any efficient supply chain is transparency of factual information derived from measurement and benchmarking. Sound information facilitates collective understanding of common problems and develops trust among stakeholders. Trust is the essential element needed for stakeholders to make meaningful commitments in addressing common problems.

EID Parry (India) and Mitr Pol (Thailand) are helpful case studies demonstrating that innovation happens in an environment where millers and growers constructively work together. In essence, a secure, viable and consistent cane supply is a critical success factor for any sugarcane-processing facility.

Distrust between millers and growers appears to be a global problem, which can partly be ascribed to the miller being a monopsony; i.e. the mirror image of a monopoly, where the miller is a
single buyer from many sellers (growers), who as individuals have little or no negotiation leverage with the miller in price setting. In recognition of this disproportionate economic ‘power’, governments have historically legislated local sugar industries. In Australia, abolished legislation was simply replaced with commercial agreements, achieving the same result. However, commercial agreements provide more flexibility; they are more easily changed to adapt to a dynamic market environment. Nevertheless, commercial agreements must provide a fair and robust conflict-resolution mechanism if such changes are to transpire in reality.

The concept of ‘best’ practice is a misnomer because different environments inherently require different management practices. This is particularly evident among countries, but also among on-farm fields. Effective supply chains make continuous incremental improvements in an effort to chase ‘better’ practice. In this regard, raising the performance of below average stakeholders can make significant improvements, i.e. by simply reducing performance variation.

Innovative technology, such as vehicle scheduling, GPS, etc, is available to streamline supply chains. However, difficulties associated with the effective implementation of technology are often underestimated; systems generally need to be adapted or even tailor-made for specific applications, as was the case with vehicle scheduling and logistics in Thailand and South Africa.

Technology adoption should preferably be guided by a supply-chain strategy because technology is the ‘accelerator/enhancer’ of business strategy. The question that arose was ‘who drives supply chain strategy?’. The answer that emerged was R&D! For example, BSES (Australia) questioned the sustainability of sugarcane agriculture in yesteryear, which led to the development of BSES’s new cropping system as the current foundation of the Australian sugarcane supply-chain strategy. In practice, R&D organisations need to work concurrently on business strategies and new technologies, but the first should provide a lead for the second, where at some point a consolidated ‘package’ is presented to industry for adoption (this could be ‘turn key’ or ‘iterative’ in nature).

The new BSES cropping system advocates: (1) green-cane harvesting and trash blanketing; (2) breaking the monoculture with increased fallow periods and/or legume break crops (given recent fertiliser prices, ‘free’ legume nitrogen has significant value); (3) controlled infield traffic; and (4) minimum tillage. If heavy infield machinery is used, it is unlikely that the full potential benefits of this system will be realised. Improvements in precision guidance technologies for harvesting and haul-out operations have accelerated/enhanced this strategy. The system is management intensive.

Supply-chain R&D should identify current and future challenges/opportunities, and then provide a suite of solutions to enable industry to meet/capture these challenges/opportunities. It was noted that ‘breakthrough’ R&D is uncommon, and meaningful progress is more often achieved through trial and error, so it is important to make a start! Actual implementation preferences are usually the sole preserve of industry itself.

This session was criticised as having too many diverse speakers that made it difficult to integrate the subsequent discussion. Two shorter sessions would have been more appropriate.

**Workshop Session 3—Research**

Three presentations were made: ‘Experiences from Mitr Phol, Thailand’ by Pipat Weerathaworn (Mitr Phol, Thailand), ‘Experiences from CTC, Brazil’ by Nilson Boeta (CTC, Brazil) and ‘Experiences from BSES, Australia’ by Eoin Wallis (BSES, Australia). Questions raised in the subsequent discussion were:

1. research organisations lead change but how do they ascertain the direction they take?
2. research is an investment not a cost; how can this message best be communicated to stakeholders?
3. human capital is ‘everything’ to a research organisation; how can this resource be optimised for best effect?
(4) how can researchers best influence the strategic intent of an organisation, or vice versa?

(5) research is worthless if results are not implemented; how can technology transfer be improved?

(6) is collaboration relevant in an environment of intellectual property protection?

Some of the salient points emanating from the discussion and questionnaires received were:

Mitr Phol (Thailand) and EID Parry (India) are both large, independent milling companies that own and operate sugarcane research facilities and that make substantial investments in the sustainability of sugarcane supply. This is necessary to maintain the viability of their milling operations because both milling companies are largely supplied by resource-poor small-scale farmers who have been unable to collectively establish effective sugarcane research and sustainability programs of their own.

Mitr Phol (Thailand) started as a single sugar factory and is now a multi-national (significant investments in China), multi-faceted (includes raw and refined sugar, cogeneration, ethanol, paper milling, logistics companies and others) conglomerate, including its Sugarcane Research Centre. The company’s Board of Directors largely dictates strategic direction for the Sugarcane Research Institute within the context of the larger conglomerate, driven by the mandate to maximise shareholders’ profit. The result is a focused and accountable Sugarcane Research Centre involving a wide range of research activities, such as agronomic practices, development of new cane varieties, processing properties associated with different varieties, processing of sugar and ethanol, production of cogeneration and biodegradable plastics, etc. Strategic focus and accountability is more difficult for research organisations that do not have a profit maximisation mandate and/or a relatively homogenous Board of Directors that mostly operate within the context of one organisation.

Research centres that have a governing body comprising individuals from diverse backgrounds with varied interests (e.g. independent miller and grower fraternities) often result in little or no strategic direction being agreed by the governing body and/or increasing reliance on the management team to guide strategy through the ranking and allocation of research funding, with the governing body having an oversight and approval role. However, management teams cannot formulate a strategic research direction effectively if they have to compete with other research organisations for limited funding from numerous funding agencies with different agendas. Strategic research direction can be absent or vague or unrelated to stakeholder profits that often remain confidential. In such an environment, fewer ‘industry’-funded research centres are expected to facilitate better strategic research direction. Without this, industry ‘needs’ are unlikely to be met, resulting in a ‘disconnect’ between industry and the research centres.

This ‘disconnect’, according to most delegates, is prevalent to some degree in most industries. Such ‘disconnects’ can be mitigated by: (1) researching economic value-adding industry ‘needs’; (2) eliminating research on uneconomic industry ‘wants’; and (3) quantifying the economic return of R&D outcomes (i.e. R&D is an investment and not a cost). This can be achieved by employing ‘economic/commercial’ skills at research centres that can better communicate in the ‘language’ of industry. Further mitigation measures include increased participation of stakeholders at strategic stages in the iterative R&D planning process.

Part of the Australian ‘disconnect’ arises from industry’s dissatisfaction with limited productivity improvements arising from R&D, where productivity is defined as tonnes cane per hectare. This is also true of other industries around the world. In this context, research centres need to reinvent their marketing/communication approaches because in the absence of R&D and its associated technology transfer, productivity would otherwise have been in decline, and productivity
benchmarks should be used in conjunction with economic related benchmarks to ensure that research centres speak the same language as industry. Economic benchmarks might be more meaningful, but are more elusive; they require a clear definition and explanation. A growing international trend is to replace historical productivity R&D objectives with a ‘vision of sustainability’, from a collective economic, environmental and social perspective. More attention needs to be given to this topic at future ISSCT Management Workshops.

CTC (Brazil) has a unique challenge in that its membership base and demand for its services is growing at an accelerating rate (CTC had 29 member mills in 2004 and 155 in 2008). Its principal response has been to decentralise its technology transfer operations to: (1) improve response times by reducing travel times (and associated travel costs); (2) improve relationships with local millers and growers; and (3) develop regional specialists to meet regional needs. The disadvantage with this approach is that regionalised technology transfer is isolated from centralised R&D, which CTC have countered by implementing a sophisticated web-based intranet that provides remote web-based training of staff, millers, growers and other stakeholders through e-learning programs and technical seminars. As a consequence, CTC has been able to partially outsource some technology-transfer functions.

Some of CTC’s key focus areas are to: (1) better identify and address sustainability needs of the industry; (2) hire, train and retain motivated staff; (3) foster partnerships and collaboration at all levels of the business; and (4) better market the value of CTC to existing and new potential members.

The effectiveness of technology transfer was raised as a concern in most industries. CTC’s web-based services are appropriate in the current ‘electronic era’, but more sociological research needs to be undertaken to increase the effectiveness of this approach as it is expected to be context specific. A global challenge for technology transfer is overcoming grower perceptions that extension advice is ‘quasi’ academic, having little bearing on the real challenges of growing sugarcane and, therefore, advice is discounted. Context specific web-based services might be helpful in this regard, because technology transfer becomes demand-led as opposed to supply-led!

Workshop Session 4 – Special Projects

Four presentations were made: ‘Biotech sugar crops and their market dynamics’ by Charley Richard (Sugar Processing Research Institute, USA), ‘A strategy to facilitate the commercialisation of GM sugarcane’ by Warren Males (Queensland Sugar Limited, Australia), ‘Managing multiple environmental challenges in Florida’ (Canegrowers Cooperative, USA) and ‘Accreditation for sustainability: proposals for international concern’ by Tim Wrigley (CANEGROWERS, Australia). Questions raised in the subsequent discussion were

1. what can be done to prepare the international sugar market for sugar production from GM sugarcane?
2. what role is there for international collaboration in promoting market access for sugar from GM sugarcane?
3. is ‘consumers are becoming increasingly aware of their environmental footprint,’ a valid statement?
4. what are some of the important environmental challenges facing sugar value chains? and
5. how can ‘better management practices’ be marketed in an effort to promote sugar?

Some of the salient points emanating from the discussion and questionnaires received were:

Potential sugar industry benefits through biotechnology include increased sugar and by-product revenue per tonne of cane, together with increased stability of production, and lower cost of
production per tonne of cane (e.g. weed, pest and disease resistance, drought tolerance, etc.).

Many markets across the globe are sceptical of biotechnology. As a consequence, a Sugar Industry Biotech Council (SIBC) has been established in North America, with its core leadership comprising the American Sugarbeet Growers Association, Beet Sugar Development Foundation and the National Sugar Cane Research Effort. Further representation comprises all North American sugarbeet growers’ associations, sugarbeet processors and marketers, sugarbeet seed companies, beet by-product marketers, sugarcane growers and processors, and technology providers. This entire group meets twice a year, but the leadership has conference calls every second week on issues related to strategic planning, issue management, information development and ‘sugar is the same’ (more about this later).

SIBC provides science-based information regarding technological advances in both sugar beet and sugarcane crops and communicates the broad range of environmental and consumer benefits of these advances. Part of this has included the commissioning of independent and accredited laboratories to scientifically test that there is no difference between sugar derived from GM sugarbeet or sugarcane, and (2) that there is no protein and/or DNA in sugar. The robust and conclusive results were affirmative, demonstrating that ‘sugar is the same’! Managing perceptions is critical.

The area planted to commercial biotech sugarbeet varieties in the US is increasing steadily. Despite the establishment of the International Consortium for Sugarcane Biotechnology (ICSB) in the early 1980s in association with the ISSCT, no commercial GM cane varieties are currently grown anywhere in the world, although South Africa, Brazil, Australia, Colombia, Argentina and the US have experimental plots. Guatemala, Mauritius, India and others are also working towards biotech varieties. A major constraint to the release of commercial biotech cane varieties is how trait providers can release a return from a vegetatively propagated crop. In the absence of commercial seed companies, industry itself needs to bear the commercialisation costs, including lawsuit insurances, countering anti-biotech campaigns and correcting market misinformation, particularly among existing and potential customers.

Commercialisation steps include: (1) obtaining regulatory acceptance in the home country; (2) building acceptance within the industry and developing market support; (3) influencing stakeholder perceptions (industry, consumer and public at large) using factual science-based information; (4) developing segregation and identity-preservation standards and procedures; and (5) facilitating commercial uptake and adoption at the local level. A helpful quote that was made in this context was ‘biotech crop varieties may provide a solution to rising food prices and increasing food scarcity and malnutrition as the world’s population continues to rise’.

With similar objectives as the SIBC in North America, the Australian industry has established the Sugarcane Gene Technology Group to specifically commercialise biotech sugarcane varieties (i.e. separate from the underlying R&D). As ‘sugar is the same’ and the challenges are common, the key to commercialising sugarcane biotech varieties is collaboration. Other industries are encouraged to engage in this process.

Environmental concerns and awareness is increasing in all sugarcane industries but the levels of concern and awareness differ. Such concerns and awareness are particularly acute in the south Florida (US) agricultural landscape where sugarcane contributes 73% of gross value. Current issues include: (1) water quantity and quality including high levels of phosphorus, nitrogen and pesticides; (2) air quality arising from cane burning, ash nuisance and perceived health concerns; (3) use of herbicides and pesticides and their effects on natural flora and fauna; and (4) habitat loss for indigenous species and the increase of exotic species.

The south Florida agricultural community, however, has an impressive history of proactively managing their environment. Various best management practices have been established
and coupled with a comprehensive suite of monitoring and performance evaluation systems. The result is that bird populations are larger, there are similar numbers of fish and more indigenous species of all taxa measured in agricultural fields than in non-agricultural areas. Invasive plant species are intensively controlled.

The Better Sugar Initiative (BSI), in association with World Wildlife Fund (WWF), has embarked upon a best-management-practice accreditation system for sugarcane agriculture internationally. The question was posed whether the ISSCT should be the lead agency in this regard. This was not supported because the nature of environmental concerns varies significantly among industries and within industries and, therefore, a single set of best management practices is not appropriate, and secondly, ISSCT is a voluntary, non-profit body that derives benefits for its members through collaborative activities that are of a non-binding nature. The BSI initiative has the potential for conflict, which might compromise the collaborative objectives of ISSCT. ISSCT, nevertheless, has a significant role to play in the sharing of information.

**Review and future of the ISSCT Management Workshop**

Qualitative and quantitative data were obtained from the workshop questionnaire, with 25 responses (61%) from 10 countries. Figure 1 indicates that all aspects of the workshop were well received.

![Figure 1](image-url)

**Fig. 1**—Impressions of delegates from the questionnaire.

Considerable qualitative data were also forthcoming, some of which was contradictory! The principal criticisms received include:

Presenters need to be encouraged to send their presentations to the organisers earlier so that all the print outs can be made available at the meeting.

The number of presentations should be limited to a maximum of three per session, or fewer, so that discussion time is not compromised and discussion remains topic-focused.

Chairing a discussion requires strong leadership. The chair needs to both challenge the presenters more and draw ‘quieter’ delegates into the discussion. As an aid to providing focus and structure to the discussions, the chair should refer more often to each session’s initial guideline questions, which should facilitate consensus outcomes.
The content of the discussions is valuable and, therefore, needs to be recorded better.

Despite these criticisms, delegates overall were complimentary (as supported by Figure 1) with special mention made regarding the venue, organisation and program including many delegates being complimentary of the session chairs and the outcomes achieved in the discussions. Suggested topics for future workshops include:

The R&D fraternity should drive the agenda in terms of identifying 3–4 R&D priorities for the next 10 years and expose the skills and resources that senior R&D management can use to increase the effectiveness and uptake of their R&D programs.

Sharing the experience and business strategies of large multi-national sugarcane-related companies (e.g. EID Parry and Mitr Phol, but there are many others), together with service providers such as Syngenta/Monsanto, Dedini/Praj, etc, is helpful, particularly with reference to the adoption and role-out of renewable energy (especially co-generation and ethanol). Non-sugarcane related experiences might also be helpful.

Technology transfer and extension need to be revisited, particularly with respect to the increasing trend of ‘traceability’ for compliance to an accredited set of better management practices; e.g. the Better Sugar Initiative (BSI). Determining success and failure factors through case-study analyses would also be helpful in facilitating new implementation/adoption strategies for novel technologies and/or measuring extension efficiency. Benchmarking initiatives also need to be considered.

A session related to human resources was suggested by some delegates and should address issues such as attracting and retaining talent in the organisation, understanding performance management of staff and identifying training needs and training opportunities. Aligned to this is embracing change management within R&D organisations and sugar industries that may need to adapt from sugar to energy industries.

The ‘disconnect’ between R&D organisations and their stakeholders appears to be relatively common and needs addressing. Investigating the use of ‘economic/commercial’ skills that use the ‘language’ of industry needs further investigation, together with increased participation of stakeholders at strategic stages in the iterative R&D planning process.

Alternative cane payments and other incentive mechanisms to optimise delivery of quality feedstock for processing require further investigation, particularly in the context of renewable energy.

Environmental concerns are expected to escalate and should remain on the agenda.
RAPPORT SUR LE SECOND ATELIER DE GESTION DE L’ISSCT – MAI 2008

Par
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Mots Clés: Gestion, Atelier de Travail, Recherche, Filière, Marchés, Energie Renouvelable.

Resume
Le second Atelier de Gestion de l’ISSCT s’est tenu à Townsville, Australie, en mai 2008 ; 41 délégués venant de 10 pays y participèrent. Le but des Ateliers de Gestion est d’intéresser les hauts cadres de l’Industrie Sucrière à l’ISSCT et particulièrement d’intégrer la gestion dans la recherche et les nouvelles technologies. L’atelier comprenait des présentations autour d’un thème particulier, suivi de discussions interactives où les problèmes étaient identifiés et les solutions pratiques proposées. Une réunion spéciale pour les Directeurs Exécutifs des organisations de Recherches ainsi que leurs hauts cadres suivit l’Atelier de Gestion. En général, l’atelier fut un succès avec les propositions intéressantes provenant des quatre thèmes : énergie renouvelable, filière, recherches et développement (R & D) et projets spécifiques. Les sujets suggérés pour les prochains ateliers incluent : (1) l’identification de 3 ou 4 projets de R & D pour les 10 prochaines années, (2) les innovations des grosses compagnies sucrières, (3) le transfert de technologie et la vulgarisation devra être redéfini, (4) les ressources humaines doivent être revues afin d’attirer et de retenir les bons éléments dans l’organisation et revoir le type de management, (5) évaluer les talents économiques et commerciaux dans le contexte du R & D, (6) le mode de paiement de la canne en relation avec l’énergie renouvelable, (7) les problèmes reliés à l’environnement.

REPORTE DEL SEGUNDO TALLER DE GERENCIA DE ISSCT, MAYO 2008

Por
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PALABRAS CLAVE: Gerencia, Taller, Investigación, Cadena de Abasto o Proveedores, Mercados, Energía Renovable.

Resumen
El segundo taller de Gerencia de la ISSCT que se llevó a cabo en Townsville, Australia en mayo de 2008, atrajo a 41 delegados de 10 países. La Comisión de Gerencia y sus talleres procuran que aumente el rol de la alta gerencia de la industria en la ISSCT, particularmente para que integren aspectos de gerencia en iniciativas tecnológicas y de investigación. El formato del taller comprendió presentaciones sobre un tema en particular, seguido por discusiones interactivas donde los problemas se contextualizaron para buscar soluciones pragmáticas. Después del taller se realizó un foro de CEOs y personal experto de organizaciones de investigación. En general, el taller fue un
éxito con diferentes contribuciones producto de las cuatro sesiones: energía renovable, cadenas de abasto o proveedores, investigación y desarrollo (I+D) y proyectos especiales. Algunos temas sugeridos para los próximos talleres fueron: (1) la fraternidad de I+D debe identificar tres o cuatro prioridades de I+D para los próximos 10 años; (2) la experiencia y estrategias de negocios para las grandes compañías relacionadas con la producción de azúcar deben continuar; (3) revisar las necesidades que existan en transferencia de tecnología y extensión; (4) temas de Recursos Humanos relacionados a atraer y retener talento en la organización y herramientas para el gerenciamiento/manejo del cambio; (5) investigar el uso de habilidades ‘económicas/comerciales’ en el contexto de I+D; (6) estrategias de pago de caña aplicables al paradigma de energía renovable; y (7) temas ambientales.
FUTURECANE—A MAJOR QUEENSLAND EXTENSION INITIATIVE THAT ACCELERATED THE ADOPTION OF IMPROVED FARMING SYSTEMS

By

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Abstract

In 2004, Queensland Department of Primary Industries and Fisheries (QDPI&F) collaborated with BSES Limited (BSES) to launch a major extension initiative called FutureCane. FutureCane was a three year State-wide extension program with the aims of promoting a sustainable and competitive cane growing sector, facilitating change in the sugar industry and assisting members of the cane growing sector to see a clearer picture of the future. State and regional steering and management committees were put in place to overview and implement the program. The main field focus was the accelerated adoption of new farming system components identified by the Yield Decline Joint Venture (YDJV), including various combinations of legume break crops, controlled traffic and reduced tillage, with an emphasis on profitability. QDPI&F provided the expertise on economics and the agronomy of break crops such as soybean, while BSES provided the expertise on cane growing. Extension methods employed included farm demonstrations, farm case studies and whole farm economic analysis. Baseline surveys were carried out to determine the current practice and progress was reviewed annually. Although uptake was relatively slow initially, the development of a Farm Economic Assessment Tool (FEAT) hastened adoption by emphasising the focus on improved profitability rather than productivity. By 2007, significant areas of cane were being grown under the new farming system throughout the Australian industry. The area using legume break crops increased by 4020 ha, controlled traffic increased by 20 133 ha and the area of reduced tillage plant cane increased by 17 071 ha. The program demonstrated the value of working collaboratively on an industry-wide basis to achieve results. This paper outlines the management structure of the FutureCane program focusing on the Farming Systems module and the practice change that occurred in the Australian sugarcane industry during the period 2004 to 2008.

Introduction

In 2004, the Australian Government unveiled a $444m sugar rescue package for the country’s struggling sugar industry (AAP, 2004). At the same time, the Queensland State Government passed the Sugar Industry Amendment Bill 2004 relating to major reforms for Queensland’s sugar industry, and the State’s sugar package was made available. The State’s package had three focus areas: Sugar Industry Change Management Program ($13 million); Sugar Industry Innovation Fund ($10 million); and a Farm Consolidation Loan Scheme ($10 million). Implementation of the package relied on partnerships between the Queensland Department of Primary Industries and Fisheries (QDPI&F), industry, the Queensland Department of State Development, Trade and Employment (QDSDTE), and BSES Limited. The QDPI&F contribution to the Sugar Industry Change Management Program was FutureCane, which was designed to
promote a sustainable and competitive cane growing sector. Within QDPI&F, FutureCane was regarded as an Adjustment Program likely to have a better longer-term impact than any short-term financial support.

The focus of FutureCane on a more sustainable and competitive cane growing sector was very topical in the Australian industry in 2004. The industry was reeling from the impact of low sugar prices and low sugarcane yields partly due to yield losses from the disease orange rust (Magarey et al., 2003).

Juffs et al. (2004) reported a general perception within the industry that the existing framework and direction of research, development and extension of results appeared not to be delivering best practice and innovation or achieving an acceptable rate of adoption. This led the CSR Company to engage management consultants, McKinseys, to guide the Cane Productivity Initiative, a major group extension project based on adult learning principles, in CSR mill areas.

Vanclay (2004) cited 12 legitimate reasons for non-adoption of new technology for natural resource management among Australian farmers: (1) Too complex; (2) Not easily divisible into manageable parts; (3) Not compatible with farm and personal objectives; (4) Not flexible enough; (5) Not profitable; (6) Capital outlay is too high; (7) Too much additional learning is required; (8) Risk and uncertainty is too great; (9) There is conflicting information; (10) Don’t see that there is a problem (lack of appreciation of the problem); (11) Lack of physical infrastructure; (12) Lack of social infrastructure.

Sundermeier et al. (2009) surveyed farmers in the Western Lake Erie Basin Watershed in Ohio, USA and found growers adopted conservation tillage because it saved time and fuel. Extension was made more effective by recognising economics and using the popular press when delivering findings.

Declining sugar yields in Australia had been recognised since the early 1990s, when the sugar industry became concerned that sugar yield per harvested hectare had reached a plateau and was declining. This prompted the formation of the Yield Decline Joint Venture (YDJV) in 1993 to identify causes of yield decline and develop solutions to it (Garside et al., 1997).

During the period 1970 to 1990, the sugarcane cropping system in Australia had become much more intensive with a general move to more ploughout-replant with frequent, aggressive tillage and less area fallowed (Willcox et al., 2000). The more intensive cropping system also coincided with the introduction of larger harvesting and haulout equipment, which normally had track widths wider than row spacing, thereby increasing soil compaction (Kidd et al., 2007).

Work during the first seven years of the YDJV showed that breaking the sugarcane monoculture using grain or green manure legume species (Garside and Bell, 2001), reducing compaction (Braunack et al., 2003a) and minimising the amount of tillage during the fallow and in-crop (Braunack and Magarey, 2002) can individually increase the productivity of the subsequent sugarcane crops, improve soil health and rainfall capture (Bell et al., 2001) and reduce production costs (Braunack et al., 2003b).

Perhaps more importantly, results were also suggesting the synergistic effects on productivity and profitability of successfully integrating these individual components into a new farming system (Bell et al., 2003; Garside et al., 2004). However, while confidence in the ability to design a more profitable and productive sugarcane cropping system was growing, adoption of the key components of the new farming system was very slow.

In October 2004, the YDJV held three regional workshops with extension officers and farmers throughout Queensland to update industry on their findings and to hear problems being encountered in the adoption of the new farming system (Agnew, 2004, Pers. Comm.). The YDJV workshops identified the 12 top issues that were knowledge gaps hampering the adoption of the new farming system as:
(1) Cane varieties to suit wider row widths;
(2) Economic comparison between controlled traffic systems and existing systems, including case studies of farms that have made the change;
(3) Canegrub management;
(4) Marketing and communication plans;
(5) Harvesting issues including effects on cane loss, extraneous matter and soil compaction;
(6) Extension officers’ agronomic knowledge of the break crops such as soybean;
(7) Weed control and herbicides applicable to the new farming system;
(8) Application of controlled traffic for furrow irrigation systems in the Burdekin;
(9) Dynamics of soil moisture;
(10) Precision billet planter;
(11) Maintaining soil health/microbes, including growers understanding of soil health;
(12) Compaction impacts over time in controlled traffic situations.

The establishment of FutureCane

The FutureCane extension project was established in 2004 as the Queensland Department of Primary Industries and Fisheries’ (QDPI&F) $5.2m contribution to the State Sugar Package, and was timely as it helped to initiate a major roll-out of the YDJV research findings.

The task of the FutureCane project was to bring together people with the skills to put together and implement a program of work to overcome the knowledge gaps identified by the YDJV workshops and provide the economic information to hasten the adoption of the improved farming system. The project team combined the expertise of farming systems agronomists, agricultural economists, and trade and business development officers to meet specific needs of Queensland sugarcane farmers. The FutureCane project was structured such that QDPI&F and BSES Limited staff members worked in partnership to deliver services, each providing their unique skills in a complementary manner to the sugar industry.

FutureCane was set up as a three year State-wide extension program with the aims of promoting a sustainable and competitive cane growing sector, facilitating change in the sugar industry and assisting members of the cane growing sector to see a clearer picture of the future. Outcomes envisaged were:

(1) Understanding within the delivery team of farming systems Best Management Practice for cane production in each of the four growing areas across the State;
(2) Raised awareness of the benefits of adopting a farming systems approach;
(3) Design and development of a workshop program to build understanding of benefits, costs and risks of moving to a farming systems approach;
(4) Growers with a better understanding of benefits, costs and risks of moving to a farming systems approach; Growers with the capacity to make necessary changes to their system;
(5) FutureCane services delivered in partnership with other service providers, and in conjunction with other sugar related programs.

The project was overviewed by a FutureCane Steering Committee chaired by the Executive Director Industry and Investment, QDPI&F. The Steering Committee had representatives from BSES Limited, Queensland Department of State Development and Innovation, CANEGROWERS,
Department of Natural Resources, Mines and Energy, Queensland Environmental Protection Agency, Sugar Research and Development Corporation (SRDC) and the Australian Sugar Milling Council. The FutureCane project leader and the FutureCane strategy coordinator were also members of the Steering Committee.

The FutureCane State Operational Plan had ten key Strategic Areas/Sub-Projects:

1. Program management;
2. Farming systems;
3. Establish Regional Delivery Service/Staff Training;
4. Communications Strategy;
5. Industry Liaison;
6. Business Planning;
7. Change Management;
8. Industry Structures/Business Alliances and Partnerships;
9. Industry Reform and Adjustment Support;
10. Trade and development/Marketing.

A FutureCane Management Committee was also established, principally to coordinate the activities of BSES Limited extension officers and QDPI&F agronomists in the Farming Systems Sub-Project. The Committee was chaired by the Adjustment Program Coordinator from QDPI&F, and consisted of QDPI&F and BSES FutureCane project leaders, representatives of the YDJV and the relevant research program leaders from both agencies.

Farming Systems focus

Hastening the adoption of the improved farming system identified by the YDJV was the principal focus of the FutureCane project. While the improved farming system had the potential to increase the productivity of the subsequent sugarcane crop, improve soil health and rainfall capture and reduce production costs, there was also opportunity to diversify farm incomes and improve farm profit by growing break crops such as soybean for grain in some districts (Garside and Bell, 2007).

The key Actions in the FutureCane State Operational Plan under the strategic area, Farming Systems, were:

- Inform key stakeholders and cane farmers about FutureCane (its services and benefits) and appropriately involve them in the local needs analysis assessment for FutureCane,
- Identify all activities and stakeholders involved in the same field of FutureCane activities in each regional delivery area e.g. CANEGROWERS, Millers, Central Agencies, SRDC, Productivity Boards,
- Provide clients with easy access to technical expertise,
- Provide, where appropriate, one-on-one support, particularly in new areas with ‘early adopters’.
- Develop a specific Farming Systems Educational module which was linked to existing and proposed business planning activities,
- Develop region specific economic models of farming systems,
- Develop a Sugar enterprise activity plan involving a change in the farming system,
- Document current knowledge relating to best farming systems practice in cane production for each growing area,
- Provide FutureCane staff with ongoing technical support from other units within QDPI&F (e.g. Plant Sciences, Bio-security),
- Provide access to technical expertise on complementary crops, including crop agronomy, marketing opportunities and gross margins etc.
- Provide cane farming clients with ongoing support through appropriate use of discussion groups/cell groups and/or other processes,
• In each region, identify or establish groups of growers, advisers, cane productivity companies and consultants to implement and assess proposed changes to sugarcane farming systems,

• Establish one on-farm commercial paddock in at least three of the Mill areas where all components of the new farming system (permanent beds established at spacings to enable controlled traffic adoption, fallow cropping, min./zero tillage planting of cane and legumes) were adopted,

• Initiate on-farm R&D programs to develop confidence in the practicality and benefits of systems change and facilitate adoption,

• Assist landowners with the growing of complementary crops outside their experience and assess their financial performance,

• Gross margins for complementary crops developed and incorporated with marketing information for publication,

• Conduct field days, workshops and bus tours as extension tools for rotational cropping and tillage practices,

• Promote farming systems at external field days,

• Develop a Newsletter to promote activities, YDJV results and ongoing extension activities or provide FC supplement to existing regional newsletters.

**Industry Liaison Officers**

The Queensland Government (Palaszczuk, 2004) recruited Industry Liaison Officers (ILO) as local ‘sugar industry champions’ in each district. ILOs had networks in their local sugar industry and worked with the FutureCane teams to promote FutureCane activities, gather local information on sugar industry needs. They also helped to identify opportunities for collaboration between different sectors in the industry and organised venues and resources for FutureCane activities.

**Local Management Groups**

Local Management Groups (LMG) were set up in each of the four cane growing areas: Far North; Herbert/Burdekin; Mackay; South East Queensland. Staff involved in the LMGs included Business Development Officers, QDPI&F agronomists, BSES extension officers, Industry Liaison Officers, Agricultural Economists, Financial Counselors and Trade and Market Officers. The LMGs developed work plans for each area in conjunction with local industry and overviewed their implementation.

**Results and discussion**

FutureCane officially commenced in July 2004, although many staff started in November 2004 and the last staff member did not commence until May 2005. While this late start meant there were missed opportunities during the first year, workshops were held throughout the State in conjunction with the YDJV team to promote a common understanding of the improved farming system. This saw a development of momentum for the project that encouraged farmers to look at new farming systems.

During the first year, there were some concerns that increasing the area fallowed may decrease overall production from a mill area and therefore threaten mill economic viability. These fears were largely allayed by developing a key message that ‘Profitability will be followed by Production’.

In the long run, improving the profitability of the cane growing enterprise by growing cash break crops in the fallow should make the cane growing business more sustainable and reduce the losses from land not growing cane.
These concerns expressed early in the project highlighted the need for the group to be able to clearly demonstrate the impact of changing farming systems on farm profitability. From a farmers viewpoint (Loeskow et al., 2006), the major impact of some of the components of the improved farming system was to reduce costs. Minimal tillage reduced fuel costs, legume break crops reduced nitrogen fertiliser usage and good fallow management reduced weed control costs for the sugarcane enterprise. To demonstrate the impact of these changes on farm gross margins and profitability, the Farm Economic Analysis Tool (FEAT) was developed by FutureCane economists (Stewart and Cameron, 2006).

FEAT was developed primarily to compare the economic performance of different cane farming systems. The tool does this by calculating several different economic performance indicators used in the agricultural sectors, e.g. gross margins, break-even yields and prices etc, and presents them in a whole-of-farm context. The focus of the tool is to look at Return on Investment when minor or major changes are made to the farming system.

FEAT was used to conduct a number of Case Studies (e.g. Halpin et al., 2008) and was also used extensively by FutureCane extension officers and agronomists. Copies were also made available directly to growers wishing to compare a number of farming system options using their own data. Much of the success of the FutureCane project was due to the widespread availability of FEAT, which allowed demonstrations of the savings that accrued from reduced tillage and the overall value of the increased income from grain legume break crops. This capacity was especially powerful when combined with ‘personalised’ data relating to farms within an individual growing area, or in many cases with data from the investigator’s own property.

Cane growers traditionally have made decisions based on production rather than profitability. When they saw little change in production as a result of the change in farming system, they tended to be reluctant to adopt it, not realising that the biggest impact was in profitability not production. FEAT overcame this problem.

Mid-term review

A mid-term review of the FutureCane project was commissioned to assess the performance of the project and outline areas for improvement and modification. The review was carried out in May 2006 and reported that ‘FutureCane is performing well, delivering benefits to the industry and challenging those who are listening. It would also be fair to say it is doing remarkably so, given its very short life.’

The reviewers also noted that ‘Its success is related to: (1) good leadership and management; (2) high quality staff; (3) a good working relationship between the participating agencies; (4) clear dovetailing of FutureCane with other industry programs; (5) a robust information base; (6) useful tools; (7) diverse and appropriate methods; (8) a main focus on industry progressives’.

The mid-term review suggested a number of changes to improve or modify the project, with the FutureCane Steering Committee endorsing a series of actions to facilitate change implementation. Specific recommendations were as follows -

- Improved consultation with all stakeholders at the levels of Steering Committee and regions.
- Facilitate reviews of the report by all regional groups so they may identify and commit to ways of improvement most suitable to their circumstances.
- Explore the feasibility and desirability of aggregation of the BSES part-time contributions into full-time commitment.
- Development of a strategic communications program to ensure all influencers are well aware of FutureCane, its bases and objectives, to widen awareness and encourage change by all growers, and record learnings of the project to date so that successors may be supported through them.
• Continue to support the first tier of innovators so they may implement the changes, and co-opt their support in reaching out to the growers who are sensitised but not yet changing.

• Consider establishment of, for example, awards for profitability and innovation, funded by industry or allied commercial interests.

• Continue to challenge growers by use of activities which take them out of their own circumstances, and expose them to relevant things outside their business, such as through bus tours to other areas and other industries.

• Look for and use all available ‘hooks’ to attract attention of growers, such as succession planning, the lifestyle benefits available from adoption of FutureCane recommendations, high fuel costs, water scarcity etc.

• Capitalise on interest in farm systems to introduce business analysis and management, and vice versa.

• Work with industry agencies to undertake an industry-wide benchmarking exercise to underpin and encourage ongoing beneficial change.

• Help build the capacity of all service providers so they may encourage and assist growers to change.

• Design and offer programs of activities for specific groups within the grower segment e.g. new and younger growers, women, large farms etc.

• Continue development and promotion of FEAT.

• Strengthen FutureCane’s attention to natural resource management and forge collaborative arrangements and activities with relevant agencies and groups.

• Undertake a risk analysis of the supply chains of the various complementary crops suitable as break crops, so to identify gaps and plan for their remediation.

• Review and redirect the activities of the ILOs to gain higher value through better matching of their skills to industry needs.

• Ensure all staff were fully familiar with the YDJV results as they continue to build through ongoing research, including FutureCane trials.

• Consider providing staff with the opportunity to enhance their capabilities in facilitation of change management and capacity building.

• Manage the risks associated with the identified threats to the project.

**Farming system change**

The level of adoption of new farming system principles in the various cane growing regions was monitored throughout the project. The area of fallow legumes, controlled traffic and zonal tillage in 2007–08 compared to 2003–04 is shown in Table 1.

<table>
<thead>
<tr>
<th>Farming practice</th>
<th>Year</th>
<th>Wet Tropics</th>
<th>Herbert</th>
<th>Burdekin</th>
<th>Central</th>
<th>Southern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fallow legumes</td>
<td>2003–04</td>
<td>1850</td>
<td>300</td>
<td>1100</td>
<td>500</td>
<td>550</td>
</tr>
<tr>
<td></td>
<td>2007–08</td>
<td>2365</td>
<td>510</td>
<td>400</td>
<td>900</td>
<td>3250</td>
</tr>
<tr>
<td>Controlled traffic</td>
<td>2003–04</td>
<td>300</td>
<td>100</td>
<td>2400</td>
<td>2000</td>
<td>4400</td>
</tr>
<tr>
<td></td>
<td>2007–08</td>
<td>6033</td>
<td>1100</td>
<td>3300</td>
<td>12 700</td>
<td>6200</td>
</tr>
<tr>
<td>Zonal tillage</td>
<td>2003–04</td>
<td>1000</td>
<td>1000</td>
<td>520</td>
<td>500</td>
<td>3409</td>
</tr>
<tr>
<td></td>
<td>2007–08</td>
<td>2300</td>
<td>4200</td>
<td>7000</td>
<td>1500</td>
<td>8500</td>
</tr>
</tbody>
</table>
The area of fallow legumes increased most markedly in southern Queensland, due largely to the development of soybean and peanuts as grain crops. This development was aided by the initiation of projects such as Grain in Cane (Bundaberg CANEGROWERS) and the involvement of local agribusinesses, as well as through the extension activities of FutureCane.

The negative result in the Burdekin was largely a seasonal effect due to wet weather and a late finish to crushing in 2007, which left little opportunity to establish break crops before the onset of the wet season.

The area of ‘controlled traffic’ was measured by quantifying the area planted to row widths of 1.8 m or greater, row spacings that effectively matched the wheel spacings of harvesters and haulouts.

While some of this area was established without the benefits of GPS guidance, most of it was and, during the period, a system of base stations necessary for differential GPS was set up in all areas.

The subsequent adoption of auto-steer using GPS guidance on planters, tractors, harvesters and haulouts is still continuing.

The area of zonal tillage (reduced tillage) increased in all areas. While central Queensland appears to be behind in terms of growth in zonal tillage, this changed significantly in 2008–09 with large areas planted using reduced tillage system.

**Arrival of sugarcane smut—a further catalyst for change**

The sugarcane smut disease was detected near Childers in June 2006 and by November 2006 had also been found in Mackay. The economic impact of sugarcane smut on the Queensland sugar industry was assessed and ways to facilitate economic recovery were identified in a report tabled in Parliament in February 2007 (Watson, 2007).

Recommendation 6 of this report stated that the FutureCane FEAT model should be made available to all growers and be backed by sufficient technical support to implement this decision tool effectively. The FEAT model was also able to assist in the broader on-farm agronomic decisions required to maintain economic viability as growers transitioned to resistant varieties.

The recommendations from the Watson Report saw the FutureCane project superseded by the Sugarcane Smut Economic Recovery Strategy in July 2007. Skills and resources developed as part of FutureCane were redirected to help growers prepare for and recover from the smut outbreak (Gillard, 2008). The Queensland Government committed $3 million over three years to:

- Support access to, and training in, economic decision-making tools such as FEAT to assist in complex decision making required to change over to smut-resistant varieties over the next few seasons
- Extension of the best farming systems practices to assist farmers in maximising soil health, minimising input costs and managing the transition to smut-resistant varieties.

**Reasons for FutureCane’s success**

The principal reasons for success of the FutureCane project were:

- Staff from the respective agencies working together to deliver quality advice on both the break crop and sugarcane components of the improved farming system. QDPI&F agronomists brought knowledge of break crops such as soybean and peanuts to the project and BSES Limited extension officers contributed knowledge of cane growing. Knowledge was shared at regular regional and State-wide meetings and through cooperation in the delivery of extension activities.
• The guidance of the YDJV team was also a key component in the correct interpretation of research results as they came to hand throughout the project. The inclusion of YDJV representatives on the FutureCane Management Committee was the key to the close working relationship that developed.

• The development of the FEAT computer program to demonstrate the impact of farming system changes on farm profitability. Many of the benefits of the improved farming system were cost savings with sometimes little overall increase in farm sugarcane production and were therefore difficult to demonstrate. FEAT gave extension officers and growers a tool to explore options.

• The inclusion of Industry Liaison Officers in local management groups gave the local industry more ownership of the project. The ILOs used their local networks to encourage more growers to attend FutureCane extension activities.

What could have been done better?

The mid-term review highlighted some areas where the project could have been better implemented, with the key areas involving relationships with local industry in the early stages of the project. For example, some local sugar industry groups felt that they had little input into the direction of the FutureCane program in their area.

Some millers felt that the emphasis on break crops meant there would be less sugarcane to crush. Some CANEGROWER groups felt that agencies external to the sugar industry (i.e. QDPI&F) were attempting to gain the kudos for work already commenced by the industry in some regions.

More involvement of local industry in the formative stages of the project would have given local industry a clearer view of the objectives of FutureCane and the project would have received local support much sooner. As it was, the support was earned through the successes of the project.

REFERENCES


FUTURECANE—UNE INITIATIVE MAJEURE DE VULGARISATION QUI A ACCELERE L'ADOPtion DES NOUVEAUX SYSTEMES DE PRATIQUES CULTURALES AU QUEENSLAND

Par

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MOTS-CLÉS: FutureCane, Vulgarisation, Économie, Pratiques Culturales, Baisse De Rendement.

Résumé

En 2004, le Département des Industries Primaires et des Pêcheries du Queensland (QDPI & F) a collaboré avec le BSES Limited (BSES) pour lancer une initiative majeure de vulgarisation appelée FutureCane. FutureCane est un programme de vulgarisation de trois ans concernant tout le Queensland avec les objectifs de promouvoir une industrie sucrière durable et compétitive pour faciliter le changement et d'aider les planteurs de canne à avoir une meilleure vision de l'avenir. Des comités de direction et de gestion nationales et régionales ont été mis en place pour avoir une vue d'ensemble et mettre en œuvre le programme. L'objectif principal dans les champs était d’accélérer l'adoption des nouvelles pratiques culturales identifiées par le comité de Recherche sur la Baisse de Rendements (YDJV), incluant les différentes combinaisons de cultures de légumineuses, le contrôle du trafic et la réduction du travail du sol, en mettant l'accent sur la rentabilité. QDPI & F s’est occupée de l'économie et de l'agronomie des autres cultures telles que le soja, tandis que BSES a fourni l'expertise sur la culture de la canne à sucre. Les méthodes de vulgarisation employées comprenaient des démonstrations sur les fermes, des études de cas individuels et des analyses économiques globales. Des enquêtes de base ont été menées pour déterminer la pratique actuelle et le progrès a été revu chaque année. Bien que l’adoption du nouveau système a été relativement lente au départ, le développement d'un instrument d’évaluation économique pour les fermes (FEAT) a accéléré l’adoption en mettant l'accent sur une amélioration de la rentabilité plutôt que sur la productivité. En 2007, d'importantes superficies de canne à sucre ont été cultivées avec le nouveau système à travers toute l’industrie cannière australienne. La superficie sous culture de légumineuses en rotation a augmenté de 4020 ha, le contrôle du trafic a augmenté de 20 133 ha et la superficie replantée avec une réduction du travail du sol a augmenté de 17 071 ha. Le programme a démontré que le travail de collaboration entrepris sur une base à l'échelle industrielle a donné des bons résultats. Ce document décrit la structure de gestion du programme FutureCane en se concentrant sur le module des nouveaux systèmes agricoles et le changement qui s'est produit dans l'industrie australienne de la canne à sucre pendant la période 2004 à 2008.
FUTURECANE—UNA INICIATIVA DE EXTENSIÓN MAYOR EN QUEENSLAND QUE ACELERÓ LA ADOPCIÓN DE SISTEMAS DE MANEJO DE CULTIVO MEJORADOS

Por

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PALABRAS CLAVE: Futurecane, Extension, Economía, Sistemas de Cultivo, Caida de la Producción.

Resumen

En 2004, el Departamento de Industrias Primarias y de Pesca de Queensland (QDPI&F por sus siglas en inglés) colaboró con BSES Limited (BSES) para lanzar una iniciativa de gran extensión denominada FutureCane. FutureCane fue un programa de extensión estatal de tres años que se realizó con el objetivo de promover un creciente sector cañero que fuera sostenible y competitivo, facilitando el cambio en la industria azucarera y apoyando a los miembros de este pujante sector para que visualizaran una imagen más clara del futuro. Se establecieron comités estatales y regionales de dirección y manejo para dirigir la implementación del programa. El enfoque principal en campo fue la adopción acelerada de algunos componentes de los nuevos sistemas de cultivo identificados por el Esfuerzo Conjunto de Caida de la Productividad (Yield Decline Joint Venture, YDJV, en inglés) incluyendo varias combinaciones de cultivos de leguminosas de rotación o intermedios secuenciados entre cosechas, control de tráfico y prácticas culturales reducidas, con énfasis en la rentabilidad. QDPI&F proporcionó el expertaje en economía y agronomía de cultivos intermedios como la soya, mientras el BSES proporcionó su experiencia en el cultivo de la caña. Algunos de los métodos de extensión que se emplearon incluyeron: demostración en los campos, estudios de caso de fincas y análisis económicos completos de las mismas. Se realizaron encuestas de línea base, donde se determinaron las prácticas originales y se llevó un monitoreo del progreso anual. Aunque la respuesta fue muy lenta al principio, el desarrollo de una herramienta de monitoreo del campo (Farm Economic Assessment Tool, FEAT en inglés) apresuró la adopción al hacer énfasis en el enfoque de mejorar la rentabilidad en lugar de la productividad. Para 2007, se estaban cultivando áreas significativas de caña bajo el nuevo sistema de cultivo en toda la agroindustria australiana. El área con leguminosas se incrementó en 4020 ha, el control de tráfico se incrementó en 20133 ha y el área de prácticas culturales reducidas en caña se incrementó por 17071 ha. El programa demostró el valor de trabajar en colaboración a nivel de toda la industria para obtener los resultados. Este trabajo describe la estructura del manejo del programa FutureCane enfocándose en el módulo de Sistemas de Cultivo y el cambio de práctica que ocurrió en la agroindustria australiana en el período entre 2004 y 2008.
FUTURES BASED PRICING FOR AUSTRALIAN SUGARCANE GROWERS

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KEYWORDS: Futures, Pricing, Growers, Restructure.

Abstract

AUSTRALIAN cane growers can now access futures based pricing for their sugarcane. Direct access to futures market pricing has long been available to growers of commodities such as grains, cattle, cotton and others. Some sugar processors have had access to these mechanisms but, in situations where cane growing and processing are separate, cane growers have traditionally been unable to hedge the price they receive for their product as unprocessed sugarcane is not deliverable against a futures contract. In Australia, many growers have recently commenced using futures based pricing mechanisms through new cane supply contracts with their sugar mills. Tonnages of sugar are apportioned to growers based on the cane price formula. Pricing contracts are ultimately closed through the pricing platform offered by the raw sugar marketing company. In this paper the range of price mechanisms available to cane growers in Australia are examined and the implications of these for industry sustainability are reviewed. These include a new, more commercial culture, longer-term cane supply contracts, growers’ ability to manage pricing decisions in light of their knowledge of growing costs and determine, to some degree, how much of the price risk they wish to manage and how much they wish to place in the hands of others.

Introduction

Contracts describing price, quantity, quality and delivery conditions are a common feature of most, if not all, sales agreements. The international commodity trade in raw sugar is no different. Some agreements include provision for fixed price sales. However, the majority of contracts include provision for futures based pricing.

In these contracts, the price has a futures based element, a component for a physical sale premium or discount and an adjustment for the pol of the sugar. Futures based pricing enables the buyers and sellers to independently manage their exposure to the world raw sugar price, using the raw sugar futures contract on the Intercontinental Exchange, known as the ICE #11.

Raw sugar sellers hedge their price exposure by taking short (sold) futures contracts and buyers by taking long (bought) futures contracts. At the time of physical sale, the buyers and sellers agree on a futures contract against which the price for the physical raw sugar will be settled and

1 The price clause of a raw sugar sales contract would typically be:
‘The price in U.S. Dollars per metric tonne net shipping weight in bulk basis 96 degrees shipping polarisation, Cost and Freight free out ex vessel’s holds at (Port), (Country), with all costs of discharge for the Buyer’s account shall be:
An AA transaction for (No. of pricing lots) lots versus the ICE #11 Futures Contract in the (Month) (Year) position, plus a premium of U.S. Dollars (amount) per metric tonne. The price to be converted to U.S. Dollars per metric tonne by multiplying by a factor of 22.046.’
agree on a mechanism to close their futures positions. In this transaction, the gain or loss made on the futures account when the contract is closed is offset against the sales price. The net price achieved by the buyer and seller is the price at which they hedged the raw sugar. Through this futures market pricing mechanism, the price achieved by the buyer can be very different to the price obtained by the seller.

The use of futures markets to manage price risk is a key feature of farmer activity in the grains, cotton and other agricultural industries. In these industries, farmers harvest a crop that can be delivered in settlement of their relevant futures contracts. In the sugar industry this is not the case. Sugarcane and sugar beet growers produce perishable agricultural products that need further processing into either raw or white sugar before commodity trade can occur. In most instances, the processor pays the farmer for the sugarcane or sugar beet received and arranges the sale of the sugar produced. Many countries regulate their sugar market, including the relationship between sugar prices and farm gate prices, which may reduce the need for farmers to manage their own price risk. However, where farmers are exposed to the world raw sugar price, regulatory structures can reduce farmers’ ability to use the futures market to match their price and production risk with their individual risk profile.

In Australia, commercial agreements, not government regulation, determine the relationship between cane growers and the raw sugar mill they supply. Although cane supply agreements vary, in all mill areas the price of sugarcane is a function of the raw sugar price. In recent years, Queensland Sugar Limited (QSL), the company that sells 95% of Australia’s raw sugar exports, has entered agreements with its mill supplier customers and developed a pricing platform that enables mill owners and, with new cane supply agreements, their cane suppliers, to independently manage the ICE #11 component of the price they receive for up to three years ahead.

Introduction of a new QSL pricing platform

In Australia, as in most other countries, cane growers sell the cane they produce to a sugar mill. Legal ownership of the cane changes hands from grower to miller at the ‘point of delivery’, generally a rail siding or road transport loading point close to the farm. From this point, the mill owner is responsible for the cane and owns all products from it.

The price the mill owner pays for the cane is a function of the price of sugar and the sucrose content of the sugarcane. In Australia, sucrose content is measured as the CCS. The cane price formula takes the following form:

\[ \text{Price cane} = \text{Price sugar} \times \text{fn(CCS)} \]

This formula means that, although the grower is not the owner of the sugar, he or she is still vitally interested in the price outcome achieved from the sale and marketing of the product.

The price of sugar used in this formula was traditionally the average net sales price realised by QSL from its pooled marketing activities. QSL actively managed the marketing and pricing of the entire crop, including the ICE #11 component based on a risk management strategy determined by the company’s board.

Mill owners all received the same price for sugar sold by QSL and this price was, in turn, used to calculate cane values. With sugar price risk managed by QSL, individual producers’ production decisions focused on cost minimisation and productivity improvement. Producers did not have a mechanism to effectively tailor management of their exposure to sugar prices to their individual risk profiles and, when the opportunity arose, to lock in long-term prices.

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2 Often using ‘against actuals’ (AA) transactions where buyer and seller agree a price at which to close their respective futures positions.

3 Commercial Cane Sugar (CCS); an empirical measure of recoverable sugar in cane.

4 Average net price = \([\text{Gross sales revenues (ICE #11 + pol premium + physical sales premium)} - \text{QSL’s costs (marketing, storage and handling)}] ÷ \text{tonnes of sugar sold, expressed in AUD/tonne IPS.} \)
In 2005, the marketing of Queensland raw sugar was totally deregulated and all mill owners, with two exceptions, signed voluntary contracts to continue to sell all their export sugar through QSL. Building on past experience, taking advantage of the new raw sugar supply agreements that replaced the regulatory structures and relying on its sound financial structure and strong credit rating, QSL developed a new pricing platform, in conjunction with its supplier customers. Enabling the separation of price risk management from the physical marketing of raw sugar, this platform provides a mechanism that allows mill owners to manage a large part of their ICE #11 price exposure in both the current and future seasons. Most mills have made arrangements for their growers to access these facilities.

In order for mill owners and cane growers to use these pricing mechanisms, several risks have to be managed. The first is contractual; if parties are pricing into the future there must also be agreements for supply of the physical sugar over the same time period. This is achieved by supply contracts that extend at least as far as three years forward. Many cane supply contracts with mills are now ‘evergreen’, rolling agreements that remain in place for three years or more unless notice is given of their termination.

Production and financial risks must also be managed. If sugar has been priced into the future, that sugar must be physically available and the counterparty financially sound. QSL’s agreement with mills requires that, to take account of possible variations in the crop due to adverse weather events or disease, no more than 70% of the current season’s sugar be priced using its pricing mechanisms and a declining proportion of future expected crops be hedged. Mills, in turn, restrict growers’ access to pricing to no more than 60 to 70% of their crop for the current year and 30 to 50% for future years, with some variations put in place to allow for individual circumstances. The balance of production for the current year is supplied to QSL’s Seasonal Pool.

Lastly, exposure risk is to be managed. Raw sugar futures, trading on the InterContinental Exchange, sell in four main contracts; March, May, July and October^5. The Queensland sugar industry has made a significant investment in bulk raw sugar storage capacity to provide it with the ability to export sugar throughout the year. As shipping proceeds year-round, exposure to the four main ICE contracts can be managed year round.

Normal variability in crop production and sales patterns can lead to variability in the tonnage of sugar that is exposed to different ICE #11 futures contracts. QSL’s pricing platform is designed to quarantine its mill supplier customers from changes in this exposure. This is done by guaranteeing participants a fixed exposure pattern of 1:2:2:1 against the July, October, March and May contracts for the sugar they elect to price, a portion of their total production up to certain limits.

The balance of sugar is priced by QSL in the Seasonal Pool. All producers supply some of their sugar to this pool and QSL manages the exposure volatility arising from changes in production and sales patterns in this Seasonal Pool. In this way the pricing platform does not impact on QSL’s marketing activities.

The 1:2:2:1 pricing ratio means that pricing participants must have a minimum of six lots to trade. As the lot size on the ICE #11 contract is 50 short tons raw value, the minimum parcel that can be dealt with is 300 tonnes of sugar, equivalent to around 3000 tonnes of growers’ cane. As noted, mills impose limits on the pricing activities of their supplying cane growers, requiring that they contract no more than 60 to 70% of their crop for the current year and 30 to 50% for future years. This means that that, typically, a grower needs to produce over 10 000 tonnes of cane to participate on their own account, well above average production of 8184 tonnes of cane (Hooper, 2008). Mills have used the mechanisms available through the QSL pricing package to provide growers with a means of accessing the futures price risk management mechanisms.

^5 A January contract is also traded, but is not used extensively by the trade.
The QSL pricing platform offers a number of close out mechanisms to its mill supplier customers. Mills can price directly or through a bank that offers ‘over the counter’ products (OTCs) to provide access to the futures market and to credit. Where pricing is done directly participants face the possibility of margin calls (initial and variation); the requirement that money be lodged with the market operator to cover potential losses through price movements. In a period of rising prices, these can represent demands for considerable funds. In general, the pricing mechanisms offered to growers do not expose them to the requirement to fund margin calls. The margins are met by either the marketing company (QSL) or by banks who provide OTC pricing instruments and who, for a fee, assume the risk of margin calls.

In each case, mills close their futures position using the QSL pricing platform. Mill owners have likewise made available to growers a range of futures price risk management mechanisms. These can be generally classified as target price pools, call pools and grower managed pools.

Target price pools are the most popular. They allow growers to amalgamate their positions to bring trades up to minimum tonnages. Typically, mills offer growers the opportunity to price at a range of price targets set at increments of around USD 15 per tonne of sugar, expressed in AUD terms.

Growers nominate a quantity of sugar that they wish to commit at each level and, if there is sufficient sugar to meet the minimum tonnages set, the pricing order is placed. When and if the sugar price reaches this target, the contracts are priced and the sugar is hedged. Target pricing allows amalgamation of commitments so that problems with minimum tonnages can be overcome.

A ‘Call Pool’ is another mechanism some mills offer. Growers nominate a tonnage of sugar that corresponds to a multiple of the minimum number of contracts available for each contract month. They then undertake to notify the mill to price each of these contracts at a time of their choosing over the period within which these contracts are open. This allows the growers great flexibility in managing their price risks in relation to the market. This type of arrangement is subject to the minimum cane tonnages discussed above and therefore is available only to growers producing large quantities of cane.

Alternative Pools are offered by some mills. These provide growers with the opportunity to join a collective pool with a different pricing philosophy to that of the QSL Seasonal Pool. In some mill areas, growers have an opportunity to access QSL’s Aggressive Pool. Some groups have engaged independent brokers to undertake pricing on growers’ behalf, based on agreed pricing rules.

In other mill areas, representatives of growers set transparent targets relating to tonnage and price for a growers’ collective pool. A pool manager undertakes pricing when these targets are achieved. In these cases, target pricing is backed up by index pricing (pricing the same amount of sugar at regular intervals) over a defined period.

In Australia, payment for cane occurs progressively throughout the year, with up to 60% of the estimated final pay being made during the crushing season and the rest progressively over the following six months. Typically grower payment adjustments that result from pricing activity are included in the final ‘wash up’ payment made for that season.

Implications of the new arrangements

The new contracts were developed through commercial negotiation; normal commercial considerations provided the impetus. There was no external (government or regulatory) intervention.

The replacement of regulations with commercial contracts for the supply and delivery of raw sugar have enabled the development of QSL’s new pricing platform and new contracts between cane growers and mill owners for the supply of cane have improved commercial structures along the supply chain. A new, more commercial culture is emerging as producers exercise greater management of their profitability by taking greater control of both their revenue and cost flows.
Longer-term cane supply contracts have been developed. In the previous regulated environment, cane supply arrangements could change annually. As noted above, growers now contract to supply over periods from three to five years; many of these are ‘evergreen’, rolling contracts that require three year’s notice for their termination. As well as enabling forward pricing, the agreements put a contractual underpinning to district production, enabling both parties to plan ahead, knowing that cane is contracted for supply and the mill contracted to crush into the future. This provides an important basis for planning and development of infrastructure within a region. It has also allowed growers better access to finance; banks are more willing to lend for expansion if it can be demonstrated that a proportion of the farmer’s returns can be assured.

A further positive outcome of the availability of futures pricing for growers is the fundamental benefit of being able to manage their pricing decisions in light of their knowledge of growing costs. When prices are high, an understanding of the market fundamentals and drivers of future price movements will assist a grower in determining a suitable time to price their product. In times of intermediate prices, a grower’s understanding of his or her costs will inform profitable pricing decisions. Even if it were felt that the market may move higher, some might choose to cover a proportion of production at prices seen as remunerative, in case price movements were not as expected. In a low price environment, the use of the pricing mechanisms may help manage expected income levels, which may help capture profitable opportunities and ameliorate any losses.

Bringing an understanding of price drivers and possible future price movements to growers can be challenging, but represents an opportunity for service providers. In the previous regulated environment, pricing and marketing was carried out by a single statutory body; producers received a pool price and had little influence on price outcomes achieved. The new structures mean that producers are no longer interested bystanders, but active participants able to manage the majority of their price outcome. Producers are compelled to take direct interest in market drivers.

All price environments involve risk. The point of departure is how those risks are managed. In the previous environment, Queensland producers relied on QSL’s price risk management services and received a pooled price outcome. The new structures enable individuals to make their own pricing decisions. In doing so, they have an opportunity to balance their own attitude towards risk and assessment of market conditions with their cost structures to secure bottom line value.

Individual decision making brings with it potential for reward and the potential for loss. Individual growers can now determine, to some degree, how much of the price risk they wish to manage and how much they wish to place in the hands of others. QSL’s pool management options will continue to be a significant part of growers’ choice into the future. Because the volatility of production and sales patterns needs to be managed, all QSL suppliers will continue to have exposure to QSL’s Seasonal Pool.

Alternative crops have made inroads into traditional cane lands in some regions. Several mill owners are using the QSL pricing platform to provide pricing options to entice growers back into the industry. Figure 1 is an example of a newspaper advertisement in an area that is using futures pricing as an incentive to encourage increased planting of sugarcane. The ability to lock in a proportion of the crop’s value even prior to planting is seen by many as giving sugarcane growing a competitive advantage over alternative crops.

Data on uptake of grower pricing is not comprehensive. This, in itself, is a reflection of the fact that these arrangements are made between growers and mills directly and do not need outside interference to coordinate or codify. Privacy and commercial confidentiality limit the public availability of data. However, it is clear that grower uptake of the new schemes has been enthusiastic. Over 95% of growers have access to some pricing mechanism. Collective pools price all grower sugar in three mill areas and some sugar in three others. Target pool pricing is the most popular mechanism for pricing in those mill areas where it is available, with around 80% of growers participating. There are variations in uptake of pricing in these areas, reflecting a typical spread of
innovators, early adopters, early majority and so on. In one area, 80% of growers are reported as having taken a position in pricing; other areas report up to 60% of growers pricing typically 40% to 50% of their expected crop for the next season.

Fig. 1—Advertisement from CANEGROWERS Bundaberg newsletter (Anon., 2009).

**Conclusion**

The availability of futures pricing in the Australian sugar industry has coincided with strengthening prices on the futures market. In a sense, the introduction of grower pricing options could have not have come at a better time.

Many growers have, at the time of writing, secured at least a part of their returns for the 2010, 2011 and 2012 seasons.

The solid price foundation provides a stable base for these producers’ operations for at least this time period. The replacement of regulated structures with commercial agreements along the supply chain has enabled the development of these price mechanisms. The benefits of the new commercial structures are significant.

These include a new, more commercial culture, longer-term cane supply contracts, growers’ ability to manage pricing decisions in light of their knowledge of growing costs and to determine, to some degree, how much of the price risk they wish to manage and how much they wish to place in the hands of others. That the changes have occurred in a strong price environment is an added bonus.

**REFERENCES**


PREVISIONS DE PRIX POUR LES PLANTEURS DE CANNE A SUCRE AUSTRALIENS

Par

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MOTS-CLÉS: Prévisions, Prix, Planteurs, Restructuration.

Résumé

LES PLANTEURS de canne à sucre australiens peuvent désormais prévoir les prix qu’ils pourraient obtenir pour leur canne à sucre. Un accès direct à l'évaluation du marché à long terme est depuis longtemps disponible pour les producteurs de matières premières telles que les grains, la viande bovine, le coton et autres. Certains producteurs de sucre ont eu accès à ces mécanismes, mais, dans les situations où la production de canne et l’usinage sont séparés, les planteurs de canne n’ont jamais pu vendre en avance leur production car leur produit non transformé ne peut être considéré pour un futur contrat. Récemment, en Australie, de nombreux planteurs ont commencé avec l’aide des mécanismes de tarification à s’engager dans des nouveaux contrats de fourniture de canne à sucre avec leurs usines. Les tonnages de sucre sont répartis parmi les planteurs selon la formule établie du prix de la canne à sucre. Les contrats de tarification sont finalisés par l’intermédiaire de la société de marketing qui vend le sucre roux. Dans cette présentation sont examinés les différents mécanismes de prix disponibles aux planteurs de canne en Australie, et les implications de celles-ci pour la durabilité de l’industrie sont discutées. Cela inclut une nouvelle approche commerciale avec des contrats de fourniture de cannes à plus long terme, la capacité des planteurs à gérer les décisions tarifaires en connaissance des coûts, et à déterminer, dans une certaine mesure, combien de risque de prix qu'ils souhaitent gérer et combien ils souhaitent placer entre les mains des autres.
ESTABLECIMIENTO DE PRECIOS BASADOS EN FUTUROS PARA LOS PRODUCTORES DE CAÑA AUSTRALIANOS

Por

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PALABRAS CLAVE: Futuros, Precios, Productores, Reestructura.

Resumen

LOS PRODUCTORES de caña australianos pueden establecer ahora los precios de su azúcar basados en futuros. El acceso directo al mercado de precios de futuros ha estado disponible para los productores de materias primas como granos, ganado, algodón y otros. Algunos productores de azúcar habían tenido acceso a estos mecanismos, pero en situaciones donde la producción de caña y el procesamiento de la misma están separados, los productores, tradicionalmente, no tenían acceso a proteger el precio que recibían por su producto debido a que la caña sin procesar no se distribuye en contratos de futuros. En Australia, muchos productores han comenzado a usar mecanismos de precios basados en futuros a través de nuevos contratos para proveer caña en las fábricas. Las toneladas de azúcar son distribuidas proporcionalmente a los proveedores basados en la fórmula del precio de la caña. Los contratos de precios son cerrados a través de la plataforma de precios ofrecida por la compañía de mercadeo de azúcar crudo. En este trabajo se revisa el rango de mecanismos de precios disponible para los productores de caña de Australia y se revisan las implicaciones de éste en la sostenibilidad de la industria. Estas incluyen, una cultura nueva, más comercial, contratos con los proveedores a plazos más largos, habilidad de los productores para conducir sus decisiones de precios a la luz de su conocimiento de los costos de producción y determinar, hasta cierto grado, cuanto riesgo ellos desean manejar en el precio y cuánto desean poner en las manos de los otros.
REGIONAL SIMULATION APPROACH FOR EVALUATING A NEW SUGARCANE VARIETY USING SYSTEM DYNAMICS

By

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KEYWORDS: Simulation Model, System Dynamics, Strategy.

Abstract

The sugarcane industry is a complex system involving sugarcane growers and sugarcane mills. Technical evaluations whose purpose is the restructuring of sugarcane production must be based on a systematic methodology. The National Agricultural Research Centre for the Kyushu Region in Japan is trying to breed a new type of sugarcane which has early maturing and high ratoonability. Such a sugarcane variety would bring a trade-off between lower sugar content, an important quality of sugarcane, and a long-term increase in the sugarcane raw material supplied by sugarcane growers to mills. Against this backdrop, a simulation model was developed based on system dynamics that accounted for the area required to cultivate a new sugarcane variety and the first date on which the sugarcane mill operations would begin. This model regards sugarcane growers and the sugarcane mill located in a given area as a single entity. A crucial factor in this model is the pol value, which increases gradually in weekly increments until it reaches a peak mid-season and then declines. Furthermore, the simulation uses five ratoon cycles / years. The model consists of three units, each with ‘Cropping’, ‘Quota’, and ‘Evaluation’, where the output includes sugarcane production volumes, raw sugar volumes, and profitability (production costs per raw sugar unit). A scenario analysis showed a decrease in profitability during the first two years, but pointed to an increase in the third year. This suggests that the change would benefit both sugarcane growers and mills. Analysis of various scenarios will help in formulating strategies for the sugarcane industry by enabling mid- and long-term forecasts.

Introduction

Introducing new technologies that result in radical reforms in sugarcane production tends to be met with resistance, due to the complexity of the sugarcane industry, which makes it hard to grasp and evaluate the effects of new technologies. One such technology is the new type of sugarcane variety which has an early maturing capacity currently being pursued in Japan (Sugimoto et al., 2001; Irei et al., 2005).

Simulation analysis is suitable for assessing such complex systems. Among various simulation analysis methods, a system dynamics approach was used because it accounts for temporal factors and permits quantitative evaluations. System dynamics was developed in the 1950s to help corporate managers improve their understanding of industrial processes, and is currently being used throughout the public and private sector for policy analysis and design. This approach is ideal for evaluating various factors in complex systems such as the global computer model ‘World3’ for the Club of Rome (Donella et al., 2004). It is therefore considered an appropriate tool for analysing a complex system such as the sugarcane industry.
In the sugar industry, MAGI is one of the most advanced simulation systems currently available (Le Gal et al., 2003). MAGI has the following features: (1) It handles processes ranging from farming to milling; (2) the simulation is based on weekly increments; and (3) it emphasises distribution efficiency. MAGI is designed primarily to evaluate changes in sugarcane production, the reorganisation of mills to which sugarcane is supplied, changes in delivery rules, and changes in supply chain capacity. These characteristics make MAGI a useful tool for managing the complexities inherent in the sugarcane industry. MAGI has already seen use as part of management efforts to improve the sugarcane industry (Lejars et al., 2008; Le Gal et al., 2008). However, MAGI can simulate at most a period of one year. This is inadequate for modelling the effects of changes in sugarcane production over several years. Another simulation tool was needed to evaluate multiple ratoon cycles of sugarcane.

An alternative approach is to base the simulation on econometric methods, which pose their own drawbacks, including a limited capacity to accommodate structural changes resulting from the deployment of new technologies. For these reasons, a simulation model was developed using system dynamics. There are many system dynamics software programs such as ‘iThink/Stella’, ‘PowerSim’ and ‘Vensim’. Vensim is produced by Ventana Systems, which offers a free introductory version of its software, Vensim PLE, which can be downloaded from the web and was the software of choice in this study.

Characteristics of sugarcane production in Japan

In Japan, sugarcane is harvested from winter to spring. With declining sugarcane production volumes, the duration of operation of sugarcane mills has also declined. This has resulted in the concentration of harvesting tasks, the most time-consuming and labour intensive stage of sugarcane production.

Cultivation typically involves two principal operations: spring-planting, summer-planting, with ratooning taking place after both the harvest of spring-and-summer planted sugarcane. The summer-planting yields a crop every other year, offering consistent and high yielding but poor land use efficiency (Table 1). In response, current efforts focus on increasing the ratoon-based crop to boost sugarcane production volumes and income for growers. Spring-planted sugarcane has a lower yield but better land use efficiency.

Table 1—Sugarcane production in Japan (2007).

<table>
<thead>
<tr>
<th>Category</th>
<th>Class</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grower</td>
<td>Number</td>
<td>27 025</td>
</tr>
<tr>
<td>Harvested area</td>
<td>Total</td>
<td>Ha 22 037</td>
</tr>
<tr>
<td></td>
<td>Summer-planting</td>
<td>Ha 8028</td>
</tr>
<tr>
<td></td>
<td>Spring-planting</td>
<td>Ha 3404</td>
</tr>
<tr>
<td></td>
<td>Ratoon</td>
<td>Ha 10 604</td>
</tr>
<tr>
<td>Average yield</td>
<td>Total</td>
<td>T/ha 68</td>
</tr>
<tr>
<td></td>
<td>Summer-planting</td>
<td>T/ha 83</td>
</tr>
<tr>
<td></td>
<td>Spring-planting</td>
<td>T/ha 58</td>
</tr>
<tr>
<td></td>
<td>Ratoon</td>
<td>T/ha 60</td>
</tr>
<tr>
<td>Harvest per grower</td>
<td>Ha/grower</td>
<td>0.81</td>
</tr>
<tr>
<td>Sugar mill</td>
<td>Total</td>
<td>Number 24</td>
</tr>
<tr>
<td></td>
<td>Raw sugar mill</td>
<td>Number 17</td>
</tr>
<tr>
<td></td>
<td>Brown sugar mill</td>
<td>Number 7</td>
</tr>
<tr>
<td>Sugarcane production</td>
<td>Total</td>
<td>T 1 498 869</td>
</tr>
<tr>
<td></td>
<td>Raw sugar mill</td>
<td>T 1 429 132</td>
</tr>
<tr>
<td></td>
<td>Brown sugar mill</td>
<td>T 69 737</td>
</tr>
</tbody>
</table>

Source: Kagoshima and Okinawa Prefectural Government.
Features of the new sugarcane variety

One of current Japanese breeding programs focuses on early-maturing sugarcane varieties and related cultivation methods. This approach achieves high and stable yield of new plantings based on a summer-planting operation and harvested in autumn (from October to November). This promotes sprouting in the ratoon cycle, since the weather is warmer at this time than during the ordinary harvest season. This leads to consistent ratooning and higher yields. However, sugarcane harvested at this time has lower pol values than crops harvested during the ordinary harvest season. Since sugarcane pricing is based on quality (i.e., pol value), higher pol values mean higher prices and more income for the grower. This factor has discouraged widespread cultivation of the new sugarcane variety. Sugarcane mills also prefer sugarcane with high pol values since raw sugar can be obtained more efficiently from such crops.

For this reason, earlier harvests offer no short-term incentives for either sugarcane growers or mills. We believe that this widespread and unquestioned acceptance of the idea that sugarcane must have high pol values is a major factor hampering the widespread adoption of early-maturing sugarcane varieties.

Overview of the model

Purpose of the simulation

A regional agricultural production model was designed based on an early-maturing sugarcane variety. A requirement was to formulate a scenario, despite the disadvantage in terms of pol value, offering long-term benefits not just to sugarcane growers but to sugarcane mills. A simulation explored in quantitative terms the likelihood of achieving this objective.

Features of the model

One of the features of the model is that it treats a sugarcane mill and sugarcane producers consisting of many growers as a single control constituent. Thus, the results of the simulation provide evaluation indices such as annual sugarcane production volumes for an entire area and aggregate sugar production costs per product.

In practice, the sugarcane variety and crop type selected by each grower vary widely. Dates for delivery of the sugarcane raw materials to the sugarcane mills are generally set based on grower requests. If rain prevents a harvest, the delivery schedule must be reviewed and adjusted. Among other factors, this complicates the process of delivering raw materials and the efficient operation of a sugarcane mill.

The model, however, assumes a special condition whereby sugarcane production and mill operations proceed rationally and efficiently.

The model is not designed to present a realistic situation. Instead, it produces a theoretical framework for region-specific models and provides guidelines for formulating future strategies.

Structure of the model

Changes in sugarcane production have effects that persist for several years. To account for sugarcane quality, we must also consider fluctuations in pol value from harvest to harvest. Thus, we performed a five-year simulation in weekly increments.

This model consists roughly of three sectors: the cropping sector, the quota sector, and the evaluation sector (Figure 1).
The structure of the model is discussed below, based on the parameters set for the hypothetical area (Tables 2, 3).

### Table 2—Cropping hypothesis.

<table>
<thead>
<tr>
<th>Cropping</th>
<th>Harvest area</th>
<th>Ratoon</th>
<th>Yielding</th>
<th>Pol curve</th>
<th>Quota priority</th>
<th>Soil fertility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring-planting</td>
<td>300 ha</td>
<td>–</td>
<td>60 t/ha</td>
<td>Ordinary</td>
<td>5</td>
<td>Rich</td>
</tr>
<tr>
<td>Ratoon of spring-planting</td>
<td>1500 ha</td>
<td>5 times</td>
<td>60 t/ha</td>
<td>Ordinary</td>
<td>4</td>
<td>Rich</td>
</tr>
<tr>
<td>Summer-planting</td>
<td>300 ha</td>
<td>No ratoon</td>
<td>90 t/ha</td>
<td>Ordinary</td>
<td>3</td>
<td>Poor</td>
</tr>
<tr>
<td>Early-maturing</td>
<td>–</td>
<td>90 t/ha</td>
<td>Early-mature</td>
<td>1</td>
<td>Poor</td>
<td></td>
</tr>
<tr>
<td>Ratoon of early-maturing</td>
<td>3 times</td>
<td>–</td>
<td>90 t/ha</td>
<td>Early-mature</td>
<td>2</td>
<td>Poor</td>
</tr>
</tbody>
</table>

### Table 3—Mill hypothesis.

<table>
<thead>
<tr>
<th>Mill opening</th>
<th>January first week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw sugar production</td>
<td>Cane_weight * Pol * Recover_rate t</td>
</tr>
<tr>
<td>Recover_rate</td>
<td>86%</td>
</tr>
<tr>
<td>Proportional cost (per cane)</td>
<td>3000 Yen/t</td>
</tr>
<tr>
<td>Fixed cost (per cane)</td>
<td>8000 Yen/t</td>
</tr>
<tr>
<td>Sugarcane purchase cost</td>
<td>Domestic price of raw sugar(70 312 Yen/t) * Share of benefit for famer(48%) * Pol * Recovery_rate Yen/t</td>
</tr>
</tbody>
</table>

Source: Ministry of Agriculture, Forestry and Fisheries (2004)

**Cropping sector**

The spring-planting area is 300 ha, and ratooning is performed five times. The summer-planting area measures 300 ha and yields a crop every other year. The total available harvest area for sugarcane is 2400 ha.

For new planting, spring-planting on the 300 ha area takes precedence. The rest is planted in summer. The early-maturing sugarcane variety is planted instead of the normal summer-planting variety and is planted in the same quantities as for existing summer-plantings.

Additionally, ratooning of the early-maturing sugarcane variety is performed three times (Figure 2).
Fig. 2—Cropping model (built by Vensim).

The system dynamics model basically consists of two types of variables: ‘level’ variables that express conditions and ‘rate’ variables that express activities. In Figure 2, the area of each crop type is represented by a level variable, while each valve symbol indicates a rate variable. More specifically, Figure 2 shows that the valve opens once a year to move to the next crop stage.

**Quota sector**

The sugarcane production volume needed for the upcoming harvest is calculated by multiplying the harvest area for each crop type, which is obtained in the cropping sector, by the crop yield. The yield is 60 t/ha for spring-planting and its ratoons and 90 t/ha for both summer-planting and the early-maturing sugarcane variety. The crushing capacity of the sugarcane mill is 1500 t/day for a weekly quota of 10,500 t. As soon as sugar production begins, the volume of sugarcane raw materials needed each week is allocated in priority order.

Early-maturing sugarcane is granted highest priority. Next, ratooning of the early-maturing sugarcane variety is performed, followed by summer-planting, ratooning for spring-planting, and spring-planting, in that order. This produces a delivery schedule for sugarcane crop types.

**Evaluation sector**

The evaluation sector produces evaluation indices for sugarcane production volumes, raw sugar production volumes, and sugar production costs. Table 3 shows the parameters and relational expressions assumed.

Pol value is a factor that affects not just raw sugar production volumes, but the amount of money paid to growers. In this model, the pol value varies weekly for both the existing varieties and early-maturing variety. The early maturing variety is assumed to have a higher pol in autumn (Figure 3).
The recovery rate for sugarcane pol value was set to 86%, and the yield rate obtained by multiplying by pol and recovery rate was used to calculate raw sugar production volumes. Sugar production costs include a proportional cost, a fixed cost, and sugarcane purchase cost (Table 3). A proportional cost and a fixed cost were set based on data released by the Ministry of Agriculture, Forestry and Fisheries of Japan. Sugarcane purchase cost is calculated by relational expression using pol value. For fixed costs, we calculated total fixed costs based on total crop yields obtained in the simulation based on initial values.

Simulation results and discussion

We performed a simulation based on the introduction of an early-maturing sugarcane variety on a 200 ha area and an early start for sugar production in the first week of November. We compared the results of this simulation with the results of the simulation of the current system (early-maturing sugarcane variety not introduced and sugar production starts in the first week of January).

With regard to harvest area by crop type, the early-maturing sugarcane variety replaced summer-planting and was harvested from the second year (Figure 4).
Sugarcane production begins to increase from the third year, when the harvesting of the ratoons in early-maturing sugarcane variety begins (Figure 5). Note that actual raw sugar production volume drops from current levels in the first and second years. This is because sugar production starts earlier, but the early-maturing sugarcane variety has not reached its full potential.

Consequently, sugar production costs per raw sugar unit, a major index for sugarcane mills, rises for the first two years following the introduction of the early-maturing sugarcane variety. But from the third year, sugar production costs begin to fall (Figure 6). We compared the cost details between the current system and in the fifth year (Figure 7).

As the sugarcane and raw sugar increase, economies of scale effect to decrease average fixed cost. The decline of average fixed cost (fixed cost per raw sugar) contributes significantly to the reduction in sugar production cost per raw sugar.
Summary

A simulation model was developed and applied to sugarcane growers and sugarcane mills and simulations performed in which an early-maturing sugarcane variety was introduced. In the resulting scenarios, increased sugarcane production volumes reduced sugar production costs beginning in the third year following the introduction of early maturing varieties.

We believe introducing an early-maturing sugarcane variety will benefit a given region, and that the increased harvest area resulting from increased ratooning operations will improve income for growers. Introducing an early-maturing sugarcane variety offers potential benefits to both sugarcane growers and sugarcane mills.

Many factors affect the state of the sugarcane industry. Evaluating the potential advantages, disadvantages, or risks of any change in the status quo remains difficult. Nevertheless, system dynamics simulation makes it possible to forecast in quantitative terms the effects of such factors. The analysis presented in this paper focused on an early-maturing sugarcane variety, but the simulation method described can also be applied to other factors to help determine how to maximise the profitability of both growers and millers.

The simulation model created can help formulate strategies for the sugarcane industry by enabling mid- and long-term forecasts, which is the first step in the change management process. The second step, if these strategies are actually executed, is the implementation of efficient operational management practices. The MAGI modelling approach can help ensure the effective management of the actual implementation in the second step.

For agricultural business operators, we believe presenting analyses of various scenarios would not only allow them to select appropriate technologies and examine future countermeasures, but also help various parties build a consensus. This notion needs to be tested in the future.

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**SIMULATION D'UNE APPROCHE REGIONALE POUR EVALUER DES NOUVELLES VARIETES DE CANNE A SUCRE UTILISANT UN SYSTEME DYNAMIQUE**

Par

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**MOTS-CLES:** Modèle de Simulation, Système Dynamique, Stratégie.

**Résumé**

L'industrie de la canne à sucre est un système complexe impliquant les producteurs de canne et les usiniers. Les évaluations techniques dont le but est la restructuration de la production de canne à sucre doivent être basées sur une méthodologie systématique. Le Centre National de Recherche Agricole pour la région de Kyushu au Japon tente de produire un nouveau type de canne hâtive avec une bonne repousse. Une telle variété de canne apporterais un compromis entre la faible teneur en sucre, le rendement de la canne, et une augmentation à long terme de la matière première fournie par les planteurs aux usines. Dans ce contexte, un modèle de simulation a été développé en fonction de la dynamique du système qui calculerait la superficie nécessaire pour cultiver une nouvelle variété de
Estrategia de simulación regional para evaluar nuevas variedades de caña usando dinámica de sistemas

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Palabras clave: Modelos de simulación, Dinámica de Sistemas, Estrategia.

Resumen

La industria azucarera es un sistema complejo que involucra a los productores de caña y a los ingenios azucareros. Las evaluaciones técnicas que se realicen con el propósito de reestructurar la producción de caña de azúcar deben basarse en una metodología sistemática. El Centro Nacional de Investigación Agrícola para la región de Kyushu en Japón está tratando de desarrollar una nueva variedad de caña de maduración temprana y buena habilidad de soqueo. Esta variedad permitirá obtener un equilibrio entre el bajo contenido de azúcar, una característica de calidad muy importante en la caña y el incremento a largo plazo de materia prima despachada por los proveedores hacia el ingenio. Contra este escenario, se desarrolló un modelo de simulación que se basa en la dinámica de sistemas que toma en cuenta el área que se requiere para cultivar la nueva variedad y la fecha en que empezará la molienda en el ingenio. Este modelo considera como una sola entidad a los proveedores y al ingenio que están localizados en el área de estudio. En este modelo, el valor de la pol es crucial, el cual se incrementa gradualmente por semana hasta que llega a un pico a la mitad del período de cosecha y luego declina. Además, la simulación utiliza cinco ciclos de soque/ años. El modelo consiste de tres unidades: ‘Cultivo’, ‘Cuota’ y ‘ Evaluación’, donde la salida incluye los volúmenes de producción de caña, volúmenes de azúcar crudo y capacidad de generar utilidades (costos de producción por unidad de azúcar crudo). Un análisis de escenarios demostró una reducción de la capacidad de generar ganancias durante los primeros dos años, pero apuntó a incrementarla en el tercer año. Esto sugiere, que el cambio beneficiaría tanto a los productores de caña como a las fábricas. El análisis de varios escenarios ayudará en la formulación de estrategias para la industria de la caña permitiendo realizar pronósticos de producción a mediano y largo plazo.
RE-SKILLING WORKERS WITHIN THE MAURITIUS
SUGAR INDUSTRY REFORM PROJECT

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KEYWORDS: Human resources, Re-engineering,
Re-skilling, Re-training, Sugar.

Abstract
The African-Caribbean-Pacific (ACP) Sugar Protocol countries, of which Mauritius is a member, ceased to benefit from preferential prices for sugar exports to the European Union (EU) as from 2009. In anticipation of the changes, the Mauritian Government presented to the EU a Multi-Annual Adaptation Strategy (MAAS): 2006–2015 for the re-engineering of the sugar industry. The strategy aims to use a cluster-based model to provide efficiency and flexibility in production and marketing of outputs to enable Mauritius to remain a competitive supplier for the EU after the price reduction. The EU is playing a significant role in financing the MAAS through the EC Sugar Accompanying Measures over the period 2006–2014 and the first disbursement of funds (2006/2007) was linked to performance indicators in four areas, namely, de-rocking of lands of small holders; implementation of the centralisation of three factories; signature of contracts under the Voluntary Retirement Scheme 2 (VRS2); and provision of training for those that will make use of the VRS2. This paper concerns the fourth indicator. A profiling survey was carried out by the Regional Training Centre (RTC) in November 2006 on 3852 potential retirees to obtain information pertinent to the re-training of persons opting for the VRS2. The questionnaire covered biographic data, employment history, education, training and competencies, employee’s future plans and training needs. The results showed that 72% of the respondents were over 50 years of age and that the majority had more than 15 years experience in the sugar industry. The majority were field workers or overseers and 80% had no secondary education, 45% could not read but 72% were interested in re-skilling/training. Around 27 different courses were designed and implemented according to the retirees’ needs in areas such as gardening, vegetable production, plumbing, food production and driving. The performance indicator of 1500 retirees receiving training by 31 December 2007 was achieved.

Introduction

Sugar protocol
Mauritius has benefitted from preferential prices for its sugar exports for over 30 years. The ACP/EU Sugar Protocol (an emanation of the Lomé Convention) was signed in 1975 and provided for guaranteed access to the EU market for fixed quantities of ACP sugar at preferential prices over an indefinite period of time. Out of the 18 ACP Sugar Protocol countries, Mauritius had the largest allocation, which was 507 000 tonnes of sugar annually. This represented 94% of Mauritian sugar exports (and this corresponded to 25% of the EU’s sugar imports). In 2006, there was a review of the EU Sugar Regime as the EU restrictive trade practices did not comply with WTO rules on level market treatment. This led to the unilateral denunciation by the EU of the Sugar Protocol that will

**Multi-Annual Adaptation Strategy (MAAS)**

In expectation of these drastic changes the Mauritian Government presented to the EU a Multi-Annual Adaptation Strategy (MAAS): 2006–2015 for the re-engineering of the sugar industry. The sector had to be transformed into an integrated sugarcane industry that would optimise the production of higher-value sugars, increase electricity production from bagasse and develop ethanol production (Autrey and Tonta, 2005). The strategy aims to use a cluster-based model to provide efficiency and flexibility in production and marketing of outputs to enable Mauritius to remain a competitive supplier to the EU after the price reduction. The overall objective of the Adaptation Strategy is to ensure the commercial viability and sustainability of the sugar sector for it to continue fulfilling its multi-functional role in the Mauritian economy, but at a significant social cost. The strategy provides for a set of measures/projects aiming at increasing the country's revenue, optimising the use of by-products, maintaining the social welfare of low income groups of the sugar industry, while fully taking into account the social and environmental implications.

The Sugar Industry Efficiency (SIE) Act was amended in 2007 (GOM, 2007) in order to accommodate the MAAS strategies. The main focus was to reduce labour costs and create a more flexible workforce. This entailed the voluntary retirement of an estimated 6000 persons. The age of workers eligible for the VRS2 was brought down from 50 years to 45 for women and from 55 to 50 for men. Voluntarily retired workers were to be provided with a compensation package of a maximum 2 months salary per year of service and a plot of land with basic infrastructure. In addition, the new regulatory framework facilitated the use of seasonal labour which was previously not permitted. Moreover, prior to the voluntary retirement of an employee, he/she had to be provided re-skilling/training opportunities for eventual redeployment into other economic sectors or support for the setting up of a small enterprise within the agricultural or non-agricultural sector.

**Accompanying measures**

In order to support the adjustment process of ACP countries affected by the sugar reform, the EU is assisting these countries through a mechanism known as the European Commission (EC) Sugar Accompanying Measures (EC, 2005; EC, 2007). Funding is provided for country-specific strategies, which lead to sustainable adaptation and hence the MAAS was accepted by the EC as the basis for the restructuring of the Mauritian sugar sector. The disbursement of funds is linked to performance indicators in four areas:

- the de-rocking and preparation of 300 ha of land belonging to small planters;
- the closure of three sugar mills;
- signature of an initial number of contracts under the VRS2; and
- the provision of a social package, including re-training and re-skilling, to 1500 workers leaving the industry.

This paper is concerned with the fourth indicator, namely the re-training and re-skilling of 1500 workers leaving the industry.

**Profiling exercise**

In November 2006, in anticipation of the re-skilling project, the Regional Training Centre (formerly known as the Robert Antoine Sugar Industry Training Centre), in collaboration with the Mauritius Sugar Producers’ Association (MSPA), members of the Personnel and Industrial Relations Officers’ Committee of MSPA (PIROC) and trade union representatives, developed a profiling survey questionnaire to facilitate the matching of the training needs and levels of literacy
of the potential VRS2 beneficiaries with existing and novel training courses. The questionnaire covered biographic data, employment history, education, training and competencies, employee’s future plans and training needs. Training was then provided for all the Human Resource Managers / Personnel Officers of the sugar companies involved in the VRS2 who were to carry out the profiling exercise.

The profiling survey covered 3852 potential retirees from 24 different sugar companies. An individual analysis for each company and a combined analysis for all of the companies was conducted. The combined results showed that 72% of the respondents were over 50 years of age, and that 85% of the potential retirees were male. The age distribution is shown in Figure 1. There were, however 937 employees who were under 50 years of age.

![Age distribution of the potential VRS 2 beneficiaries.](image)

The majority of the respondents had more than 15 years’ experience in the sugar industry but many of them had over 30 or 40 years’ experience.

![Years of service in the sugar industry.](image)

The majority (80%) of the employees had only attended primary school. Only 102 employees reported having attended school up to Form V (see Figure 3).
The majority of the respondents were field workers or overseers and 80% had no secondary education. In Mauritius various languages are spoken. Literacy was reported by the potential retirees as shown in Table 1.

It can be inferred that around 45% of the potential beneficiaries could not read and 49% could not write, and this had implications for the design of appropriate re-skilling programs.

Table 1—Reported literacy in various languages (% of respondents).

<table>
<thead>
<tr>
<th>Languages read</th>
<th>Languages written</th>
</tr>
</thead>
<tbody>
<tr>
<td>French</td>
<td>55</td>
</tr>
<tr>
<td>English</td>
<td>38</td>
</tr>
<tr>
<td>Mauritian Creole</td>
<td>33</td>
</tr>
<tr>
<td>Hindi</td>
<td>10</td>
</tr>
<tr>
<td>Arabic</td>
<td>&lt; 1</td>
</tr>
</tbody>
</table>

Despite the low educational and literacy levels, 72% were interested in re-skilling/training. They were also questioned about other competencies that they believed they possessed and the most common responses were gardening/vegetable cultivation, masonry/bricklaying, plumbing, woodwork, electrician, painting, sewing, welding, fishing, mechanics and farming.

Training was designed to build upon these competencies as the ultimate objective was to facilitate eventual redeployment into other economic sectors and/or provide the basis for the setting up of small enterprises.

The potential beneficiaries were asked what plans they had for the future and 42% stated that they wanted new employment, 31% hoped to be self employed, while 14% wanted to retire from economic activities and 2% said that they wished to emigrate.

The percentage of retirees who were seeking employment after the VRS2 corresponded to the percentage who were interested in training. Concerning the new employment, the most popular responses are given in Table 2. The potential retirees were also asked to indicate what sort of training that they wanted to follow and Table 2 also shows these responses.
Table 2—Percentage of responses for choices of future employment and training.

<table>
<thead>
<tr>
<th>Future employment</th>
<th>Training</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hotel industry + Integrated resort schemes</td>
<td>18</td>
</tr>
<tr>
<td>Gardening</td>
<td>10</td>
</tr>
<tr>
<td>Agriculture/vegetable and flower production</td>
<td>10</td>
</tr>
<tr>
<td>Construction industry</td>
<td>4</td>
</tr>
<tr>
<td>Driving</td>
<td>2</td>
</tr>
<tr>
<td>Plumbing/pipe fitting</td>
<td>2</td>
</tr>
</tbody>
</table>

n = 3852

Implementation

An agreement was reached on 5 December 2007 between the MSPA and the Government of Mauritius on the industry reform process (MCA, 2008). This agreement successfully triggered the implementation of key reform measures and enabled disbursement of scheduled EU Accompanying Measures. Over 6500 employees of the sugar sector retired under the VRS2 and ERS schemes at the end of 2007. This is in addition to the 8000 people that left the industry in 2001 under the first VRS.

The Regional Training Centre was selected to be the coordinating body for the implementation of the re-skilling project. Around 27 different courses were designed (or selected from pre-existing courses) according to the retirees’ needs and level of literacy in areas such as: basic vegetable production, introduction to gardening, livestock production, plumbing and pipe-fitting, domestic electrical installation, food production techniques, housekeeping operations, basic arc welding, lorry driving, heavy goods vehicle driving, etc. All the courses were delivered in the local Creole language, used lots of visuals, and all were very practical in orientation. The course durations ranged from 27–84 hours. These courses were run at the Regional Training Centre and at various centres throughout the island in collaboration with the Industrial and Vocational Training Board of Mauritius and the Agricultural Research and Extension Unit of the Ministry of Agro-Industry, Food Production and Security.

According to the SIE Act (Amended) 2007, the training was to be provided while the beneficiary was still in employment. However, since the agreement between the MSPA and the Government of Mauritius was only reached on 5 December 2007 and the VRS2 had to be completed by 31 December 2007, it was logistically impossible to dispense all the training while the workers were still in service. It was therefore agreed that all transport costs and daily wages were to be refunded to the beneficiaries if they had to follow courses after their retirement.

Despite the time constraint, 1500 beneficiaries were enrolled on appropriate courses and were able to follow at least one training session prior to 31 December 2007 and the remaining sessions were completed in 2008. Evaluation questionnaires indicated that the retirees enjoyed the training programs and many mentioned that it was the first time that they had an opportunity to follow a course and that they were eager to put their new competencies to use.

Discussion

Had the deal between the MSPA and the Government of Mauritius been concluded earlier, the profiling data would have been used directly for the preparation of lists of trainees for each selected course. However, because of the 14 month delay, the data in the database was only partly true as, for example, the ages of respondents had changed, some people who were previously too young to obtain the VRS were now old enough to qualify, and some people changed their training...
choices, future plans, etc. Nevertheless, the profiling database was extremely useful for the planning of training courses, for the briefing of training providers about the target audience and for presentation purposes for the EC evaluators.

The feedback from the participants who followed the various training courses was positive but no data are available on how many beneficiaries are actually using their new competencies. Some of the overall objectives of the EU Accompanying Measures were to mitigate the social impact of the sugar industry adaptation strategies and to support ACP countries on their path to poverty reduction and sustainable development. In this context, the support for re-skilling was aimed at facilitating the transfer of employees from the sugar sector to other sectors of the economy. Available data show that around 13% of the beneficiaries were employed in other sectors in April 2008 but this is likely to be an under-estimate as many are self-employed. In addition, many retirees have been re-employed in the sugar sector as seasonal labour under new contracts of employment. The Government of Mauritius has set up a National Empowerment Foundation (NEF) whose aim is to broaden the circle of job opportunities for job seekers through training and placement facilities and help those whose jobs are affected by the global economic crisis. Thus VRS2 beneficiaries who are seeking jobs have been encouraged to enrol at the NEF.

The Regional Training Centre also provides training for those remaining in the industry. As the industry is being transformed into a modern integrated sugarcane industry, new skills are required. Courses and workshops have been designed to meet the new needs in areas such as new farming systems – the Australian model and the Mauritian adaptation, improving harvester performance and impact of extraneous matter on sugar and energy recovery, production of low colour raw sugar and refining technologies, as well as in management topics such as finance for non-finance managers, good corporate governance, negotiating skills, etc. The Mauritian sugarcane industry also has interests in the hotel, real estate and golf industries and therefore training in new areas such as landscape design, customer care, communication skills, sales techniques, and so on, are increasingly sought after.

Although much of the information in this paper is local in nature, it is possible that the processes used by Mauritius could be used as a model for other countries undertaking re-skilling programs in the context of sugar reforms. The European Union is obliged to assess utilisation of funds on an annual basis and reallocates them among protocol countries if the money is not spent as planned. Since the key performance indicator of 1500 retirees following training by 31 December 2007 was achieved to the satisfaction of the EC evaluators, disbursement was not impeded.

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RECONVERSION DES TRAVAILLEURS DE L'INDUSTRIE SUCRIERE
DANS LE CONTEXTE DU PROJET DE REFORME
DE L'INDUSTRIE SUCRIERE MAURICIENNE

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Résumé

LES PAYS signataires du Protocole Afrique-Caraïbes-Pacifique (ACP), dont Maurice est membre, a cessé de bénéficier de prix préférentiels pour les exportations de sucre vers l'Union européenne (UE) à partir de 2009. En prévision de ces changements, le Gouvernement mauricien a présenté à l'UE un «Multi-Annual Adaptation Strategy (MAAS): 2006-2015» pour la restructuration de l'industrie sucrière. La stratégie vise à utiliser un modèle de regroupement pour fournir l'efficacité et la flexibilité de la production et la commercialisation de produits permettant à Maurice de rester un fournisseur compétitif pour l'UE après la réduction de prix. L'UE joue un rôle significatif dans le financement de la MAAS, à travers des Mesures d'Accompagnement pour le sucre au cours de la période 2006–2014 et le premier décaissement des fonds (2006/2007) est lié aux indicateurs de performance dans quatre domaines, à savoir l’épierrage des terres des petits propriétaires, la mise en œuvre de la centralisation de trois usines, la signature de contrats dans le cadre du plan de retraite volontaire 2 (VRS2), ainsi que la prestation de formation pour ceux bénéficiant du VRS2. Ce document concerne le quatrième indicateur. Un sondage a été réalisé par le Regional Training Centre en Novembre 2006 sur 3852 retraités potentiels afin d'obtenir des informations pertinentes quant à la reconversion professionnelle des personnes optant pour le VRS2. Le questionnaire portait sur les données biographiques, historique de l'emploi, l'éducation, la formation et les compétences, les plans futurs des employés et leurs besoins en formation. Les résultats ont montré que 72% des bénéficiaires ont plus de 50 ans et que la majorité a plus de 15 ans d'expérience dans l'industrie sucrière. La majorité était des laboureurs ou des surveillants et 80% n'ont pas d'enseignement secondaire, 45% ne savent pas lire, mais 72% étaient intéressés à la reconversion et à la formation. Environ 27 cours différents ont été conçus et mis en œuvre en fonction des besoins des retraités dans des domaines tels que le jardinage, la production maraîchère, la plomberie, la production alimentaire et la conduite de divers véhicules. L'indicateur de performance de 1500 retraités, qui ont reçu une formation avant le 31 décembre 2007, a été atteint.
RE-CAPACITANDO A LOS TRABAJADORES EN LA INDUSTRIA AZUCARERA DE MAURICIO PROYECTO DE REFORMA

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Resumen

LOS PAÍSES que conforman el Protocolo Azucarero África-Caribe-Pacifico (ACP), del cual Mauricio es un miembro, dejaron de beneficiarse de los precios preferenciales de la exportación de azúcar a la Unión Europea (UE) en 2009. Anticipándose a los cambios, el gobierno de Mauricio presentó a la UE una Estrategia de Adaptación Multi Anual 2006–2015 (MAAS por sus siglas en inglés) para efectuar la re-ingeniería de la industria azucarera. La estrategia promueve el uso de un modelo basado en un cluster para dar eficiencia y flexibilidad en la producción y mercadeo de los productos que le permitan a Mauricio permanecer como un proveedor competitivo para la UE después de la reducción de precios. La UE está jugando un papel muy importante en el financiamiento del MAAS a través de Medidas de Acompañamiento del Azúcar en el período 2006–2014 y el primer desembolso de fondos (2006–2007) estuvo ligado a los indicadores de desempeño en cuatro áreas: eliminación de rocas en tierras de los pequeños participantes, implementación de la centralización de tres fábricas, firma de contratos bajo el Esquema de Retiro Voluntario 2 (VRS2 por sus siglas en inglés), y provisión de entrenamiento para aquellos que harían uso del VRS2. En el presente trabajo se describen las actividades de este cuarto indicador. En noviembre de 2006, el Centro de Capacitación Regional realizó una encuesta de perfiles a 3852 candidatos potenciales a retiro para obtener información pertinente de la re-capacitación de personas que optaran al VRS2. El cuestionario incluía datos biográficos, historia de empleos, educación, entrenamiento y competencias, planes futuros de los empleados y necesidades de capacitación. Los resultados mostraron que el 72% de los encuestados, tenían más de 50 años y la mayoría tenía más de 15 años de experiencia en la industria azucarera. La mayoría eran trabajadores de campo o supervisores y el 80% no tenía educación secundaria, 45% no podían leer y 72% estaban interesados en ser re-capacitados/entrenados. Se diseñaron e implementaron alrededor de 27 cursos de acuerdo a las necesidades de las personas en el estudio, incluyendo áreas como jardinería, producción de vegetales, plomería, producción de alimentos y manejo. El indicador de desempeño de contar con 1500 candidatos a retiro recibiendo capacitación para diciembre de 2007 se cumplió.
USING COMPUTER SIMULATION MODELS TO AID REPLANT PLANNING AND HARVEST DECISIONS IN IRRIGATED SUGARCANE

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KEYWORDS: Replant Planning, Information Technology, Simulation Modelling.

Abstract
LARGE commercial sugarcane operations face complex replant planning decisions. The replant operation is costly and limited resources must be employed where they are likely to produce the largest yield improvement. These decisions are complicated further by the need to evaluate the benefit across multiple cutting seasons. Typically, replant field selection is based on historical performance, and poorest yielding fields on poorer soils tend to be prioritised for replant. However, this approach might not maximise estate-wide productivity. The decision making process needs to consider: which fields should be selected for replant in which season; what varieties should they be replanted back to; and what long-term harvest sequence should be followed to minimise harvest age effects; to maximise sucrose production in current and future seasons. A replant planning decision support framework was developed in CanePro, a commercially available Agricultural Management System, to assist with this complex task. Field selection was made by benchmarking actual field cane yields against potential yields discounted for soil type and ratoon using a soil type/ratoon matrix. Climatic potential yields were estimated using a simplified version of the CANEGRO crop simulation model. Each field’s ideal replant ratoon age was estimated by maximising the total (across all fields) of the average (across all ratoons) expected yield of each field. Fields were assigned a replant date based on their ratio of current to ideal replant ratoon age within the estate’s replant capacity constraints. Replant variety selection was made by optimising overall sucrose performance in a season using variety-specific sucrose curves. The harvest sequence was adapted to maximise overall sucrose production. To evaluate the methodology, four seasons of historical field data were obtained from a commercial operation in Swaziland. Actual estate practice was compared with the replant recommendations made using the CanePro framework. The relative performance of the scenarios was evaluated by comparing the overall sucrose yield simulated for each scenario. A 0.6% improvement was attributed to the CanePro field selection algorithm and a further 0.6% to the harvest sequencing algorithm.

Introduction
Large irrigated commercial sugarcane operations form the backbone of many sugar industries in Africa, Latin America and Asia. Typically, these estates comprise one or more factories supported by miller-owned and managed nucleus estates. Often these agricultural operations are responsible for the bulk of mill supply and are used to ensure rateable delivery during the milling season. Estates range in size between 10 000 and 60 000 hectares but, on average, are between 10 000 and 20 000 hectares, typically made up of 1000–5000 fields. Management is usually well structured and competent, and required to meet strict production and budgetary targets.
The management of an operation this size is inherently complex, especially long-term replant decisions and variety selection following plough-out. Yield in successive ratoons tends to decline due to reductions in stalk population and mass, and an increase in stalk mortality (Chapman, 1988). The rate of yield decline depends on a range of factors, some inherent and others due to management practices employed (King et al. 1965). Inherent factors include sugarcane varietal characteristics and the crop’s growing environment including climate, soil structure and inherent fertility. Examples of management factors include soil compaction, nutrition, water management, disease management etc.

The decision to replant a field is principally an economic one. At some point, maintenance of a ratoon crop under a certain yield may not be profitable (Bakker, 1999). A number of methods have been proposed to establish an optimum replant ratoon age based on economic considerations (Chinloy and Shaw, 1973; Hoekstra, 1976; Keerthipala & Dharmawardene, 2001; Simms, 1982). However, these methods are difficult to integrate into a whole estate management plan and generally fail to acknowledge the limitations imposed by an estate’s capacity to replant in term of replant period(s) and capital constraints on plant and equipment. The replant decision on these estates changes from one of optimum replant age, to one of maximising estate-wide productivity given a limited replant capacity. Limited resources must be employed where they are most likely to produce the largest overall yield improvement. These decisions are further complicated by the need to consider their effect on current and future seasons.

**Estate practice**

Replant planning involves three primary decisions. Firstly, which fields to select for plough-out, secondly, what varieties to plant fields back to and, thirdly, an optimum harvest sequence to satisfy a plough-out calendar while maximising average harvest age and overall sucrose production.

Current estate practice tends to prioritise fields based on their absolute performance in isolation. Fields on inherently weaker soils tend to be replanted more frequently. This practice assumes that replanted fields attain a similar plant yield irrespective of inherent soil limitations. This is often not the case and more productive fields are often overlooked. Additional considerations confound field selection decisions. Probably the most important constraint to the replant operation is capital which restricts the area that can be replanted annually. Management also need to consider other issues including changes to field layout, irrigation system redesign priorities and estate variety composition which could take precedence over purely agronomic considerations.

Variety selection following plough-out appears to be well managed on these estates. Most estates have a clear understanding of how varieties perform during the season, have identified a long-term variety composition strategy and select varieties to satisfy seasonal differences and soil suitability within the constraints of an ideal variety plan.

Harvest planning tends to be confined to the current harvest season. Field sequencing is usually only finalised prior to the season start and the harvest age of plough-out fields is often sacrificed to ensure that harvest dates coincide with replant periods.

In an effort to address some of these limitations and improve the decision making process around replant planning, a decision support framework was developed in CanePro, a commercially available agricultural management information system (MIS) widely used in the industry.

**CanePro**

Decision support systems of this nature lend themselves to an MIS. An MIS can cope with the large amounts of historical data required to assess field performance and integrate the decision making process over a large area and multiple cutting seasons.

CanePro is a sugarcane-specific MIS developed by SQR Software, a software development company based in South Africa. CanePro has been adopted by a large number of commercial estates...
in Africa and Central America. The system provides general management functionality such as field and agronomic record keeping, resource utilisation and planning, labour control and payroll, but also more specific decision support tools including irrigation scheduling, harvest planning and field performance benchmarking functionality. These tools make use of components of CANEGRO, a crop simulation model developed in South Africa.

CANEGRO is a daily time-step model developed along the lines of the IBSNAT (International Benchmark Sites Network for Agrotechnology Transfer) models for maize, wheat and soybean (Inman-Bamber, 1991, 2001; O’Leary, 2000). CANEGRO has been incorporated into the latest DSSAT (Decision Support System for Agrotechnology Transfer) suite of crop simulation models and is being validated internationally (Singels et al., 2008). Models of this nature have developed to the point that they are becoming increasingly valuable in addressing strategic and technical issues in sugarcane agriculture (Inman-Bamber et al., 2001).

CANEGRO is principally climate driven. The daily inputs can be obtained from a standard meteorological station measuring rainfall, radiation (or sunhours), temperature, wind speed (or run), and a measure of vapour pressure deficit. Under irrigated conditions, potential sugarcane yields can be defined as the capacity of the crop to utilise radiation and temperature without bias (Liu and Kingston, 1995). This potential yield estimate provides a benchmark yield against which actual yield can be evaluated.

**Methodology**

**Potential and attainable yield benchmarks**

Individual field performance for a particular harvest season can be evaluated by comparing actual yield against potential yield simulated for the duration of that crop. This performance ratio can be used to compare field performance without the bias imposed by seasonal growing conditions, both within a season and between seasons. This is a useful benchmark, but fails to acknowledge the decline in yield with successive ratoons and the rate at which yield declines on poorer soils relative to more productive soils. Process-level models such as CANEGRO are calibrated and validated on well-managed small-plot experiments and are currently unable to simulate ratooning ability and some management effects which are unavoidable in a commercial operation. To cater for these effects, a soil/ratoon matrix was developed to discount potential yields based on soil type and ratoon number. Estate-specific matrices were calculated by comparing actual and potential yield by ratoon for fields within defined soil types. Potential yield, corrected for soil type and ratoon, provided a second benchmark, termed attainable yield potential, against which actual yields could be evaluated (example in Figure 1).

**Replant planning**

The ratio of actual to attainable yield was considered a useful tool when ranking fields to be considered for plough-out and replant, and is a key element of the replant planning framework implemented in CanePro. The average value of this ratio over the last five cycles has been adopted as an indicator of a field’s performance, and is assumed to continue to apply into the future, whether the field is replanted or not. The expected cane tonnage from a given field can then be estimated as the product of

- The field area;
- The field performance ratio;
- The relevant entry in the soil/ratoon matrix; and
- The potential yield

The potential yield is determined entirely by the meteorological conditions over the growing period. For longer-term decision making on replanting, we replace the potential yield by an annual
average value based on long-term mean meteorological data. Under this assumption, only the first three items in the list above are field-specific.

The first objective of the replant planning algorithm presented here is to assign a maximum ratoon age (i.e. ideal long-term ratoon age at which to replant) to each field such that

- The total (across all fields) average (across all ratoons) expected cane tonnage (as defined above) is maximised; and
- The average area replanted per annum does not exceed the limit for the estate.

The replant planning module of CanePro includes an algorithm to solve this optimisation problem. It accepts as inputs: the area and field performance ratio of each field; the maximum area that can be replanted per season and the soil/ratoon matrix. The output is the ideal maximum ratoon age of each field. As one might expect, fields whose entries in the soil/ratoon matrix show a slow decline in yield with increasing ratoon are typically assigned a high maximum ratoon age, corresponding to infrequent replanting. Fields whose performance ratios are below average also tend to be replanted less frequently because the lower performance ratios will still apply after plough-out and hence reduce the benefits of replanting.

The field selection algorithm implemented in CanePro sorts the fields in decreasing order of the ratio of actual ratoon age to ideal maximum ratoon age. The fields at the top of the list are assigned the first available planting season until the replant capacity is fully utilised. A field is overlooked only if its age at the required cut date makes it a poor choice. The algorithm then proceeds to the next season in the planning period.

**Variety selection following replant**

The algorithm used to assign cane varieties to ploughed-out fields aims to maximise total sucrose production subject to any constraints on the variety mix. The sucrose content of cane will typically show seasonal characteristics that depend on the cane variety. A polynomial curve was fitted to historical data on sucrose content by time-of-year for each cane variety. The polynomial curves are used to estimate the performance of each variety on each day of the cutting season, and thereby determine the optimal variety mix. This is reconciled against the variety mix of fields not being replanted, and the remainder used to determine which varieties should be introduced on ploughed-out fields so as to yield the greatest benefit in sucrose production.

In practice, decisions on variety selection are often constrained by external factors. The variety selection algorithm accommodates constraints on the minimum and maximum areas of each variety that can be planted in each planting period, and these can be used to limit the overall variety mix.

**Field harvest sequencing**

Once fields have been identified for replanting in future seasons, the cutting plans must be modified to ensure that fields to be ploughed-out are harvested in a timely manner and at acceptable cut ages. The CanePro replant planning module incorporates a harvest planning tool that determines an appropriate cutting sequence for each season in the period of interest.

Fields identified for replant are assigned fixed cut dates in the last season before plough-out, and their cut dates in intervening seasons are assigned using a constant cut age. Fields not selected for replanting are then added to the harvest plan in such a manner that the oldest cane is cut first. In this manner, a harvest sequence that is compatible with the replant plan can be determined for each season.

An attempt was made to optimise the harvest sequence so as to maximise total sucrose production within the constraints of the replant plan. The algorithm exploits the differences in the shape of the sucrose curves by exchanging fields in the sequence where it would increase the overall sucrose yield. Fields due for imminent replanting are constrained in terms of how far they
can depart from their assigned cut dates, but the cut sequence of the remaining fields is guided by the expected sucrose production. For each field, this is estimated using the cane yield from the CANEGRO model adjusted by each field’s performance ratio and the sucrose polynomial for that cane variety.

**Case study**

A case study was conducted using data from a commercial operation in Swaziland. The purpose of the study was to evaluate and compare a number of scenarios. All scenarios were based on the same (actual) data, but differed with respect to replant decisions. All scenarios were evaluated using the same technique, viz. by estimating cane yields as described earlier and using fitted sucrose curves for sucrose yield estimation. The relative merit of the replant decisions in each scenario was gauged from the simulated total sucrose production.

**Soil/ratoon matrix**

The soil/ratoon matrix was calculated using field history records between 1983 and 2008. Soils were grouped into soil classes as defined by Nixon (1986). Only fields comprised of >80% of a single soil class were included in the analysis. The average performance ratio (actual/potential yield) by season was plotted against ratoon and a linear regression fitted for each soil class (Table 1).

As expected for a commercial dataset of this nature, the scatter was relatively large as indicated by the low correlation coefficients ($R^2$) and the large root mean squared errors (RMSE). However, all five regression models were highly significant and described the relative productivity of the soil classes in line with commercial estate experience (Figure 1).

<table>
<thead>
<tr>
<th>Soil class</th>
<th>No. values</th>
<th>Slope</th>
<th>Intercept</th>
<th>$R^2$</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I</td>
<td>243</td>
<td>0.009</td>
<td>0.900</td>
<td>0.19</td>
<td>0.09</td>
</tr>
<tr>
<td>Class II</td>
<td>65</td>
<td>0.010</td>
<td>0.811</td>
<td>0.10</td>
<td>0.11</td>
</tr>
<tr>
<td>Class III</td>
<td>249</td>
<td>0.013</td>
<td>0.873</td>
<td>0.37</td>
<td>0.07</td>
</tr>
<tr>
<td>Class V</td>
<td>80</td>
<td>0.018</td>
<td>0.870</td>
<td>0.27</td>
<td>0.11</td>
</tr>
<tr>
<td>Class VI</td>
<td>103</td>
<td>0.028</td>
<td>0.815</td>
<td>0.30</td>
<td>0.07</td>
</tr>
</tbody>
</table>

**Replant plan**

Four recent consecutive seasons of historical data were included in the study. No significant change in irrigation systems or field disposition had taken place during this time, and no fields had been ploughed out specifically to change their variety. Hence, all replant decisions during this time had been based on yield improvement.

A total of 1400 fields were included in the study and 538 of these (approximately one-third) had actually been replanted during this period. The replant periods within which planting took place (typically from July to November of each season) and the total areas replanted were determined from the historical data, and were used as a constraint on any alternative replant plan that was proposed. Similarly, the fallow periods following plough-out were typically between 8 and 11 weeks in duration, and were observed when determining dates of last harvest prior to planting.

Three scenarios were considered. The first was based on the actual replanting decisions during this period, and a second constructed using the plantings recommended by the field selection technique described earlier. A third scenario using no replanting was included for comparison purposes. In each scenario, a harvest plan was calculated for the four seasons of interest. The simulated tonnage of sucrose produced over the four seasons was then used as a measure of the relative benefit of each replant plan.
The harvest plans were calculated using actual mill crush rates, and the field harvest sequence was determined as described earlier. Fields were cut at the rate required to meet the demand for cane by the mill. The cane yield for each field was estimated as the product of its historical performance ratio and the attainable yield potential at the planned harvest date.

**Results**

The three scenarios were first evaluated using the same cane variety for all fields in all seasons. This was done to isolate the effect of the field selection by preventing small differences in the variety mix from influencing the results.

The outcomes are compared in the ‘field selection’ row of Table 2. The replant plan based on the field selection algorithm produced 0.6% more sucrose than the actual replant plan over the four seasons. However, both replant plans produced a benefit of less than two percent over the scenario having no planting. The results suggest that the field selection algorithm may be a reasonably good one, but that the scope for gains via field selection is rather limited.

A second set of simulations was conducted to test the effect of the modified field harvest sequence. These simulations made use of the full range of cane varieties. The harvest plan for each scenario was first calculated based on the ‘oldest first’ cutting sequence that is used by many estates. The scenarios were then re-evaluated using the harvest sequence optimised for sucrose production.

The results are shown in Table 2 in the ‘cutting sequence’ row. In each scenario, the modified cutting sequence produced an advantage over the standard sequence. The magnitude of the advantage depended partly on the degree to which the variety with the most distinctive sucrose curve had been incorporated in the replant plan. The plan recommended by the software considered
this a preferred cane variety, and the modified cutting sequence produced 0.6% more sucrose than the standard cutting sequence.

In each scenario, the migration of fields within the cutting sequence towards their preferred time of harvest was clearly evident when comparing the adjusted cutting sequence from one season to the next. The total sucrose produced in the first season was typically the same regardless of which cutting sequence was used. This is because the change in each field’s cutting sequence caused a departure from its ideal cut age, and this countered the benefit in sucrose yield. However, the advantage of the adjusted cut sequence increased with each season, as the cut age began to stabilise. By the fourth season, the total sucrose produced using the adjusted cutting sequence was one percent higher than when using the standard cut sequence, without any increase in cane production. These results applied equally to all three scenarios.

Table 2—Total sucrose production after four seasons estimated for the three scenarios evaluated in the case study.

<table>
<thead>
<tr>
<th>Field disposition</th>
<th>No planting</th>
<th>Actual plantings</th>
<th>Recommended plantings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total field area (ha)</td>
<td>20 992</td>
<td>20 992</td>
<td>20 992</td>
</tr>
<tr>
<td>Area replanted (ha)</td>
<td>0</td>
<td>7079</td>
<td>7029</td>
</tr>
<tr>
<td>Fields replanted</td>
<td>0</td>
<td>538</td>
<td>464</td>
</tr>
</tbody>
</table>

Field selection

| Sucrose produced with single variety (t) | 1.158 m     | 1.174 m          | 1.181 m               |
| Benefit of planting (%)                 | 1.4         | 2.0              |                       |

Cutting sequence

| Sucrose produced with all varieties using oldest-first sequence (t) | 1.160 m | 1.175 m | 1.186 m |
| Sucrose produced with all varieties using modified cut sequence (t) | 1.166 m | 1.183 m | 1.193 m |
| Benefit of sequence optimisation (%)                                      | 0.5     | 0.7     | 0.6     |

Conclusions

Although relatively small, this potential increase in productivity was obtained with no increase in expenditure. The increase in productivity can be attributed entirely to better decision making. In addition, it is worth noting that this estate is technically well managed and has access to reliable field records through the CanePro MIS to aid decision making. Yield benefits may well be greater for estates with limited access to technical expertise and poorer information availability. Providing access to technical expertise is one of the advantages offered by an MIS such as CanePro. Technically complex concepts, often not readily available to commercial managers, can be harnessed in a user-friendly interface as part of an MIS to aid commercial decision making.

REFERENCES


UTILISATION DES MODELES DE SIMULATION PAR ORDINATEUR  
POUR AIDER AUX PROGRAMMES DE REPLANTATION  
ET DE RECOLTE DANS LA CANNE IRRIGUEE  

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MOTS-CLES: Programme de Replantation, Technologie de l'Information,  
Modélisation de la Simulation.  

Résumé  

Le programme de replantation est complexe dans les grandes exploitations commerciales de canne à sucre. La replantation coûte chère et des ressources limitées doivent être utilisées pour améliorer au maximum les rendements. Ces décisions se compliquent davantage par la nécessité d'évaluer les bénéfices sur plusieurs saisons de coupe. En général, le choix du champ à être replanté est basé sur les performances passées et les champs à faibles rendements sur les sols pauvres ont tendance à figurer parmi les priorités pour la replantation. Toutefois, cette approche n’optimise pas la productivité globale de l’exploitation. La décision prise doit prendre en compte la saison dans laquelle certains champs doivent être replantés; les variétés qui devraient être replantées; et quelle séquence de récolte à long terme doit être suivie pour minimiser les effets de l’âge de la récolte et pour optimiser la production de sucre dans la saison actuelle et future. Un programme a été développé par CanePro, un système de gestion agricole disponible sur le marché, pour aider à la décision de replantation et faciliter cette tâche complexe. La sélection des champs a été faite par l'analyse comparative des rendements actuels et les rendements potentiels en prenant compte du type de sol et de la repousse. Les rendements potentiels dus au climat ont été estimés à l'aide d'une version simplifiée du modèle de simulation de culture CANEGRO. L’âge de replantation des repousses idéal de chaque champ a été estimé en maximisant (dans tous les champs) le rendement total moyen attendu (à travers toutes les repousses) de chaque champ. Les champs ont été assignés une date de replantation en fonction de leur rapport de l’âge actuel et idéal des repousses, en prenant compte des contraintes de capacité de replantation de l’exploitation. Les variétés sélectionnées pour la replantation ont été faites pour optimiser les performances globales de sucre dans une saison à l’aide de courbes pour des variétés spécifiques. La séquence de récolte a été adaptée pour optimiser la production globale de sucre. Pour évaluer la méthodologie, quatre saisons de données historiques ont été obtenues d'une exploitation commerciale au Swaziland. La pratique actuelle a été comparée avec les recommandations pour la replantation à l'aide du programme CanePro. Les performances relatives des différents scénarios ont été évaluées en comparant le rendement global de sucre simulé pour chaque scénario. Une amélioration de 0.6% a été attribuée à l'algorithme de sélection du champ fait par CanePro et une amélioration supplémentaire de 0.6% à l'algorithme de séquence de récolte.
USO DE MODELOS DE SIMULACIÓN PARA LA PLANEACION DE RE SIEMBRA Y LA TOMA DE DECISIONES DE COSECHA EN CAÑA DE AZUCAR CON RIEGO

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PALABRAS CLAVE: Planeación de Resiembra, Tecnología de la Información, Modelos de Simulación.

Resumen

Las operaciones comerciales a gran escala en las plantaciones de caña de azúcar enfrentan complejas decisiones de resiembra. La operación de resiembra es costosa y se deben utilizar recursos limitados donde se espera que produzcan una mejora significativa en la producción. Estas decisiones se complican aún más con la necesidad de evaluar el beneficio a través de múltiples cortes. Típicamente, la selección de un campo para resiembra se basa en el rendimiento histórico, y los campos con los rendimientos más bajos en los suelos más pobres son priorizados para la resiembra. Sin embargo, es posible que esta estrategia pueda no maximizar la productividad del estado o región. Este proceso de toma de decisión necesita considerar: qué campos deben ser seleccionados para resiembra en qué años, qué variedades se deben sembrar y que secuencia de corte se seguirá a largo plazo para minimizar los efectos de la edad de corte y para maximizar la producción de sacarosa en la época de corte actual y en las subsiguientes. Un marco para la toma de decisiones en resiembra se desarrolló con CanePro, un sistema de manejo agrícola comercial, para ayudar en esta tarea tan compleja. Se seleccionó el campo estudiando el rendimiento real del área contra rendimientos potenciales descontando los efectos del tipo de suelo y soca, usando una matriz tipo de suelo/soca. Rendimientos potenciales climáticos fueron estimados usando una versión simplificada del modelo agrícola CANEGRO. Se calculó la edad ideal de soca para la resiembra de cada lote, maximizando el total (a través de todos los lotes) del promedio (a través de todas las socas) del rendimiento esperado para cada lote. A cada lote se asignó una fecha de resiembra, basado en el radio de la edad actual a edad ideal de la soca para resiembra dentro de las limitantes de la capacidad de resiembra del estado. La selección de las variedades para la resiembra se hizo optimizando todo el desempeño varietal en una zafra, usando curvas de sacarosa específicas por variedad. La secuencia de corte se adaptó para maximizar la producción total de sacarosa para evaluar la metodología, se obtuvieron datos históricos de la operación comercial de 4 años para un área de Swazilandia. Las prácticas actuales se compararon con las recomendaciones de resiembra obtenidas con CanePro. El desempeño relativo de los escenarios se evaluó comparando la producción total de azúcar para cada escenario. Un 0.6% de mejora se atribuyó al algoritmo de selección de lotes de CanePro y otro 0.6% al algoritmo de secuencia de corte.
A DECISION SUPPORT APPROACH TO ADDRESS NEW SUGARCANE QUALITY-BASED PAYMENT SYSTEMS

By

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KEYWORDS: Quality Incentive, By-Products, Participatory Approach, Sugarcane, Payment Scheme.

Abstract
In sugar industries where growers and millers are independent economic entities, payment systems aim at sharing the annual sugar industry revenue. They have been designed to create incentives to improve milling performance, cane yields and quality. Like most revenue sharing agreements, they tend to be a contentious issue between growers and millers. In some industries, while modifying payment systems can be the key to increasing industry profitability, mistrust between growers and millers can hamper such improvements. The situation is now exacerbated by the development of sugarcane co-products, such as ethanol, electricity or by-products for niche markets, which can generate higher benefits than sugar, thus calling for a rethink of payment systems. This paper presents a decision support approach which aims to assess new cane payment systems while increasing revenue sharing transparency. It is based on a simulation tool called Pempa, which helps to assess the impact of new cane payment systems on growers’ revenue and on revenue sharing between stakeholders. Experiments have been carried out for 3200 growers supplying two mills on Réunion Island, to test the impact of implementing a new payment system based on a relative formula. Results showed that the simulation approach could facilitate understanding and implementation of a new payment formula, especially for multiple-purpose sugarcane.

Introduction
In sugar industries where growers and millers are independent economic entities, payment systems aim at sharing the annual sugar industry revenue resulting from the sales of sugar and all sugarcane by-products such as molasses and bagasse. They have been designed to create incentives to improve milling performance, cane quality and cane yields.

A review of sugarcane payment systems in the main sugarcane producing countries (LMC, 2002) showed that payment systems vary between, and sometimes within, countries depending on four main elements:

- Sugar and co-products price.
- Revenue sharing agreement between growers and millers. Revenue resulting from the sale of sugar is redistributed between growers and millers on a fixed basis (x% for the growers, (100-x) % for the factory) or on a variable basis (the price is defined for a standard level of quality and a fixed extraction capacity).
- A global payment formula. In all sugarcane industries, the tonnage delivered is used as a basis for payment. Tonnage can be combined with the mill average quality, a group average quality (especially for small-scale farmers) or an individual quality analysis.
• The definition of ‘sugarcane quality’ and the parameters used for quality payment. The indicator used to define sugarcane ‘quality’ differs between countries. It can be the sucrose content, an estimation of the recoverable sugar present in each tonne of cane or an estimation of the value of a tonne of cane in terms of marketable product. It can depend on elementary indicators, such as sucrose and fibre content, mill extracting capacities, materials and methods used for quality measurements, etc.

In practice, it is hard to design a ‘perfect’ payment system and guarantee that equity is always maintained while ensuring that incentives, for both growers and millers, are not distorted (Todd and Forber, 2005).

In most countries, payment systems are based on complex and sophisticated formulae. They have been built through successive historical negotiations, readjusted according to mill performance or growers' practice improvements and tend to be a contentious issue between growers and millers (Lejars, 2008).

Thus, in some industries, while modifying payment systems can be the key to increasing industry profitability (Kroes and Fadden, 2004; Higgins and Muchow, 2003; Le Gal et al., 2008; Lejars et al., 2008), mistrust between growers and millers and the fact that each of these stakeholders may not be able to clearly assess the impact of modifications in their own revenue can hamper such improvements.

The situation is now exacerbated by the development of sugarcane co-products, such as renewable energy from ethanol or electricity (Keating et al., 2002; Sutherland, 2002), fibre-based commodities (paper, packaging, etc.) or other niche products like furfural alcohol or lactic acid. Most payment systems currently aim at promoting the production of cane for sugar extraction. They encourage high sucrose content while penalising fibre rate, despite the fact that fibre can be used to produce by-products that have a higher value than sugar.

In some countries, part of the revenue from by-product sales can be allocated to growers depending on the tonnage of sugarcane delivered. However, by-product payments are independent of the quality parameters. Payment systems are generally adapted to a sector in which the main outlet is sugar. The development of multiple-purpose sugarcane, whether or not earmarked for sugar production, calls for a rethink of payment systems (Wynne, 2007; Higgins et al., 2007).

More generally for agro-industries, very few support systems have been developed to design payment systems. Some studies have been undertaken to design optimal quality price schemes (Zago, 2006), especially in wine industries (Touzard et al., 2001). Bouche and Attonaty (1999) conducted experiments on milk price elaboration to define quality standards.

As ‘milk quality’ has different meanings for different stakeholders, their objective was to build a typology to differentiate and define the different representations of quality. However, the implementation of new payment systems remains difficult and sometimes impossible when stakeholders are not involved in the decision process from the beginning and when they are not able to assess the impact of new payment systems on their own income.

This paper presents a decision support approach which aims to assess new cane payment systems while increasing revenue sharing transparency and quality incentives impacts on revenue. A software, called Pempa (Auzoux et al., 2008), has been developed in order to facilitate assessment of the impact of new cane payment systems on growers’ revenue and on revenue sharing between stakeholders.

Firstly, we focus on the method and the tool used to support payment system implementation. Then, we present an application tested in Réunion to achieve a more transparent alternative cane payment system based on a relative formula. Finally, we show how this method could be applied to alternative payment systems for multiple-purpose sugarcane in the near future.
The decision support approach

Objectives

The decision support approach aims to assess the impact of new cane payment systems on growers’ revenue and on revenue sharing between stakeholders. It is based on software called Pempa, which has been designed specifically for sugarcane industries.

The new payment formulae are developed by an expert or in partnership with stakeholders. Once stakeholders agree on the definition of sugarcane ‘quality’, the simulation tool assesses the impacts of new quality-based payment formulae on individual revenue. The purposes are to: (i) facilitate comprehension of the incentive effects of quality payment formulae, (ii) clarify the effects of new payment formulae on individual grower’s revenue, and (iii) increase transparency on value sharing between stakeholders.

Modelling structure and software

The software Pempa was developed with Microsoft Visual Basic.Net. This version does not require computer literacy and is available both in English and French. It is the subject of a data-processing patent filling and it is downloadable in free access on Internet on the website ‘www.agri-logistique.cirad.fr’. Payment scenarios can be imported from, or exported to, an Excel file. This facilitates data input and offers users considerable time savings for configuration of the payment system.

The model is based on a three level representation of stakeholders: farms, groups of farms and mills. Stakeholders’ links are represented through a pyramidal structure (Figure 1), including an elementary unit (EU), an EU group (Group) and the mill. An EU can be a farm, a part of a farm, a group of farms, etc. Each EU is characterised by their weekly deliveries and weekly quality indicators.

Cane ‘quality’ is defined through a synthetic indicator (QI), which depends on elementary indicators, such as fibre, sucrose content, or data relative to the mill process. Four quality elementary indicators and a synthetic indicator (QI) can be defined to estimate EU ‘quality’.

The payment model combines two sub-models: the first for quality parameters and the second for growers’ income (Figure 2). Through the first sub-model, the synthetic indicator is defined, and average indicators are calculated for each grower, group of growers and the mill. The quality used for payment (QP) and the global payment formula can also be determined by users. Through the second sub-model, a stakeholder’s revenue is calculated using tonnage and quality characteristics. Different sugar and co-product prices can be tested, such as different kinds of subsidies. Simulations are done on a weekly basis because the payment of growers is usually done using this time step.
Simulations of different payment systems

Users may define a large panel of payment schemes depending on:

- The synthetic indicator (QI)

  It can be modified using four elementary indicators, such as sucrose and fibre content. It can be an estimation of the sucrose content, the recoverable sugar present in each tonne of cane or the value of a tonne of cane in terms of marketable product. QI is chosen by the user and is a function of the elementary indicators (fibre, sucrose…). Various formulae for QI can be defined. This synthetic indicator can be defined on a weekly basis.

- The weekly paid quality

  The formula to calculate paid weekly quality is designed by the users and could be based on the expression of the predefined synthetic indicator, but also the mill annual average quality, the group annual average quality, the weekly mill average quality and the group weekly average quality.

- The weekly payment formula

  This synthetic indicator (QI) and the weekly paid quality (QP) can be used directly for payment or not. In a few countries, the quality paid is ‘relative’, i.e. representing the difference between the grower’s weekly results and the mill average. The formula to calculate the weekly payment can be a function of the weekly paid quality and the synthetic indicator. The formula is calculated for each EU or for each group.

- The revenue formula

  The parameters of the revenue formula (R) can integrate the three formulae before as members, but also the price of the sugar per tonne of cane, subsidies depending on tonnage or quality and the selling price of sugar or sugar by-products.
Simulation results

Pempa can be used to investigate the impacts of different payment schemes and quality incentives on growers' revenue, value sharing between growers and millers and value sharing among growers.

A wide range of issues may be addressed:

1. calculating growers’ revenue for different payment formulae, at an individual level and/or for a whole group of farmers
2. assessing the impact of modifying the parameters used in a payment formula such as sugar price, qualitative parameters, new subsidies
3. testing the impact of delivery allocation modification on growers’ income for a given payment formula
4. By comparing the results of the different scenarios, it is possible to calculate the value sharing between growers and miller and among growers. The results obtained can be analysed according to farm type or any other feature.

The tool calculates a stakeholder’s revenue on a weekly and annual time step, according to given quality delivery characteristics and payment rules. The simulation results are represented at the three levels of the mill area structure: EU, PU, and mill.

Experiments conducted in Réunion

An experiment was carried out with two mills on Réunion Island. Two different payment systems have been tested: the current one and a payment system based on a relative formula.

Scenarios

In the current system, a synthetic indicator, called ‘richesse’, is used to estimate the amount of sugar that could be extracted from cane. It depends on the sucrose content (S), juice purity (p), bagasse (b) and fibre (f) rates (Figure 3).

Growers are paid according to their weekly results QI

\[ QI = Rich = f(S, b, f, p) \]

As the ‘richesse’ (Rich) reaches a peak in the middle of the season, with this kind of payment, growers are understandably reluctant to deliver cane before or after this peak. Some growers tend to over-estimate their production at the beginning of the season, so as to have a higher weekly allocation and be able to deliver more cane in the middle of the season. Consequently, millers foresee a longer season length and do not work at their full crushing capacity at the beginning and end of the season. The extension of the milling season tends to reduce the season average sucrose content (Moor and Wynne, 2001) because the additional milling takes place at the beginning and end of the season, when the sucrose content is low.

Thus, we assessed the impact of switching from the current system to a relative one. The relative payment was designed to regulate deliveries when payment is done on a quality basis (Buchanan, 1974). In a relative payment system, growers are paid according to the difference between their quality and the weekly average of the mill. The \( Richrel_{i,k} \) indicator used for payment is:

\[ Richrel_{i,w} = (Rich_{i,w} - \overline{Rich}_w) + \overline{Rich} \]

Where

\( Rich_{i,w} \): Sugar content of grower i for week w
\( \overline{Rich}_w \): Average sugar content for week w
\( Rich \): Mill average sugar content for the whole season
The impact of modifying the payment formula was simulated for the 3278 growers indexed in the Inter-professional Centre of the Cane and Sugar (CTICS) database. Simulations were performed for four different years using data for the seasons from 2001 to 2005.

Table: Comparison of current and relative payment systems

<table>
<thead>
<tr>
<th>Current system</th>
<th>Scenario ‘relative payment’</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Quality indicators</strong></td>
<td><strong>Quality indicators</strong></td>
</tr>
<tr>
<td>In the current system, cane ‘quality’ depends on the sucrose content (S), juice purity (p), bagasse (b) and fibre (f) rates.</td>
<td>Idem</td>
</tr>
<tr>
<td><strong>Synthetic indicator</strong></td>
<td><strong>Synthetic indicator</strong></td>
</tr>
<tr>
<td>A synthetic indicator, called ‘sugar content’, is used to estimate the amount of sugar that could be extracted from cane. It depends on the sucrose content (S), juice purity (p), bagasse (b) and fibre (f) rates. It includes specific coefficients depending on the measurement methods (E) and rates used as reference (fr: reference fibre rate; pr: juice purity rate).</td>
<td>Idem</td>
</tr>
</tbody>
</table>

\[
QI = \text{Rich}_i = \frac{S \times (1 - b)}{E} + \frac{5(f_r - f)}{100} + \frac{(p - pr)}{100}
\]

<table>
<thead>
<tr>
<th><strong>Weekly quality paid</strong></th>
<th><strong>Weekly quality paid</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Rich (w_i)</td>
<td>Rich(rel) (w_i) = (Rich(w_i) - Rich(o)) + Rich(o)</td>
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<table>
<thead>
<tr>
<th><strong>Weekly payment</strong></th>
<th><strong>Weekly payment</strong></th>
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<tbody>
<tr>
<td>(P_{w,i} = \frac{Po(\text{Rich}_i - 5.8)}{\text{Rich}_o - 5.8})</td>
<td>(P_{w,i} = \frac{Po(\text{Rich}_{rel,i} - 5.8)}{\text{Rich}_o - 5.8})</td>
</tr>
</tbody>
</table>

With \(\text{Rich}_o\): reference sugar content; \(Po\): Price of a tonne of sugarcane with sugar content \(Ro\)

<table>
<thead>
<tr>
<th><strong>Growers’ revenue</strong></th>
<th><strong>Growers’ revenue</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>(R_i = \sum_{w=1}^{l} P_{w,i} \cdot T_{w,i} + \text{Subs 1} \times \text{Trot} + \text{Subs 2})</td>
<td>Idem</td>
</tr>
</tbody>
</table>

With Subs1: subsidies depending on tonnage
Subs 2: subsidies depending on EU

Results

The analysis showed that switching from one payment to another (Figure 4):

- Did not modify the division of proceeds between millers and growers.
- Slightly modified large-scale growers’ revenue.
- Could modify small-scale growers’ income by around 20%.

Fig. 3—From the current system to a relative payment.
We then identify and characterise the growers who were highly affected by the payment modifications. We showed that:

- For most of them, losses were offset from one year to another. Only 8% of the growers lost part of their revenue every year.
- Growers who lost more than 10% of their income were those who systematically delivered more sugarcane at the middle of the season.

As expected, the simulations showed that the relative payment system would encourage growers to deliver cane regularly throughout the season. These results were discussed among stakeholders.

The discussion process highlighted the necessity to investigate a new scenario based on regular deliveries. We thus simulated a modification in the tonnage delivered each week by these 10% of growers who systematically delivered more sugarcane at the middle of the season.

We showed (Figure 5) that, if they delivered regularly, milling capacity utilisation could be improved.

The season length could be reduced by one or two weeks. A reduction of two weeks could increase the total sugar production and total revenue by 4%, without any additional investment for millers or growers.

When the simulations were run on an inter-annual basis, we showed that a relative payment system and a season reduced by two weeks increased the revenue of all the growers (We supposed that logistics costs are not modified).
Consequently, simulations showed that the relative payment system would encourage growers to deliver cane regularly throughout the season, resulting in improved utilisation of milling capacity and a potential 2-week reduction in the season length.

**Discussion**

Pempa should be used in collaboration with stakeholders involved in sugarcane payment system elaboration and outsiders such as researchers or consultants.

Scenarios should be designed with a steering committee that at least includes growers’ and millers’ representatives, as this sort of issue requires participation and agreement of every stakeholder’s group.

Once stakeholders have agreed on the payment system to be studied or modified, scenarios are configured and can be simulated using the software. The scenario outputs are compared mainly on the basis of individual revenue and value sharing.

The simulation tool promotes discussion between grower and miller representatives on potential changes in payment systems. It provides information that enhances and facilitates the negotiation process between stakeholders.

The purpose of the tool was to better formalise payment systems and value sharing among stakeholders. The simulations and the stakeholders’ participation provided greater insight into both the nature of relative cane payment and opportunities for improving industry efficiency by adopting such a system.
Conclusions and prospects

The division of proceeds between growers and processors may lead to conflicts between the two groups. Modelling and simulation could considerably increase transparency and facilitate the implementation of new payment schemes, with the support of professionals and researchers, providing a quick and reliable way for assessing and comparing alternative scenarios.

Pempa makes it possible to evaluate new payment formulae, designed and developed in partnership with sugar industry stakeholders. This tool enables their evaluation and facilitates their comprehension while clarifying their individual effects.

Pempa could be used to support implementation of new payment scheme designed for multiple purpose cane (sugar, electricity, ethanol, etc.). At this stage, we do not have an example of a quality-based payment system for multi-purpose sugarcane. However, once a formula or a set of potential formulae are designed, PEMPA could be used to support implementation of a new payment scheme designed for multi-purpose sugarcane.

Profits and their distribution between the stakeholders can be calculated for each use. However, this step must be accompanied by an analysis of parameters that should be considered to evaluate the ‘quality’ of cane for products other than sugar.

Moreover, this tool could be further extended by including other parties involved in production and processing within the supply chain, particularly hauliers and independent workers, who are paid on a tonnage basis whereas their work has an impact on the product quality. The current software is designed to include these other parties, which could be paid through a different payment formula.

REFERENCES


UNE APPROCHE D’AIDE A LA DECISION POUR METTRE EN OEUVRE DES NOUVEAUX SYSTEMES DE PAIEMENT BASE SUR LA QUALITE DANS LA CANNE A SUCRE

Par

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MOTS CLÉS: Incitation, Qualité, Sous Produits, Approche Participative, Canne à Sucre, Méthode de Paiement.

Résumé

Dans les industries sucrières où les planteurs et les usiniers sont des entités économiques indépendantes, les systèmes de paiement visent à partager les revenus annuels de ces industries. Ils ont été conçus pour créer des incitations afin d’améliorer les performances d’usinage, les rendements et la qualité des cannes. Comme la plupart des accords pour le partage des revenus, ces systèmes causent parfois des litiges entre planteurs et usiniers. Dans certains secteurs, le changement des systèmes de paiement peut être la clé pour accroître la rentabilité de l’industrie mais la méfiance entre planteurs et usiniers peut entraver ces améliorations. La situation s’est aggravée aujourd’hui avec le développement des coproduits de la canne à sucre, comme l’éthanol, l’électricité ou les sous-produits pour des marchés ciblés, qui peuvent générer des bénéfices plus élevés que le sucre, ce qui amène à revoir les systèmes de paiement. Les auteurs présentent une approche d’aide à la décision pour évaluer les nouveaux systèmes de paiement de canne à sucre avec plus de transparence dans le partage des revenus. Il est basé sur un outil de simulation appelé Pempa, qui aide à évaluer l’impact des nouveaux systèmes de paiement de canne sur les revenus des planteurs et du partage des revenus entre les parties concernées. Des expériences ont été effectuées à la Réunion pour les 3200 planteurs fournissant des cannes à deux usines pour tester l’effet de la mise en œuvre d’un nouveau système de paiement basé sur une formule relative. Les résultats ont démontré que l’approche de simulation pourrait faciliter la compréhension et la mise en œuvre d’une nouvelle formule de paiement, en particulier pour les multiples produits de la canne.
UN ENFOQUE DE SOPORTE DE DECISIONES PARA TRATAR SISTEMAS DE PAGO BASADOS EN CALIDAD

Por

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PALABRAS CLAVE: Incentivo de Calidad, Co-Productos, Estrategia de Participación, Caña de Azúcar, Esquema de Pago.

Resumen
EN LAS industrias azucareras donde los productores de azúcar y los productores de caña son entidades económicas independientes, los sistemas de pago están encaminados a compartir el retorno anual de la industria. Estas se han diseñado para crear incentivos para mejorar el desempeño de la molienda, la productividad en campo y la calidad. Tal como sucede en la mayoría de convenios donde se comparten ganancias, se crea rivalidad entre los productores y los ingenios. En algunas industrias, mientras la modificación de los sistemas de pago ha sido la clave para mejorar la rentabilidad de la industria, la desconfianza entre los productores y los ingenios puede ensombrecer las mejoras. La situación está ahora agravada por el desarrollo de co-productos de azúcar, como el etanol y la electricidad o los otros productos para nichos de mercado específicos, que pueden generar beneficios más altos que los del azúcar, lo que llama a replantear los sistemas de pago. Este trabajo presenta una estrategia para la toma de decisiones que promueve la búsqueda de nuevos sistemas de pago mientras se incrementa la transparencia en la distribución de ganancias. Está basada en una herramienta de simulación llamada Pempa, que ayuda a evaluar el impacto de nuevos sistemas de pago en las ganancias de los productores y en la distribución de retornos entre las partes interesadas. Se llevaron a cabo experimentos para 3200 productores de caña que proveen materia prima a dos ingenios de la Isla Reunión, para evaluar el impacto de la implementación de un nuevo sistema de pago basado en una fórmula relativa. Los resultados mostraron que la estrategia de simulación podía facilitar el entendimiento y la implementación de una nueva fórmula de pago, especialmente cuando la materia prima se usa para diferentes propósitos.
THE CARBON FOOTPRINT OF SUGAR

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KEYWORDS: Carbon Footprint, Energy, Sugarcane, Sugar, Ethanol.

Abstract

Climate change is rapidly becoming a serious issue and one which will increasingly demand the attention of sugar producers. Estimation of the greenhouse gas emissions in the production of sugar, otherwise known as the carbon footprint, is an essential part of any sustainability study. A method of estimating net energy usage and greenhouse gas emissions has been developed, based initially on work done on biofuels. The calculation routine was developed for use in the Better Sugarcane Initiative standards, which focus on the sustainability of the sugarcane industry. This estimation procedure estimates primary energy requirements including both direct effects, mainly energy usage, and indirect effects, which include energy used in the production of fuels, fertilisers and chemicals. Allowance is also made for the inclusion of direct land use change effects. The estimation procedure allows for the production of molasses and/or ethanol, and for the export of power. Attention is given to the potential errors and problems in arriving at these estimates. The main problems are uncertainties in emissions from fertiliser use and the way in which emissions are allocated to co-products. The results show that the carbon footprint is most affected by sugarcane yield, sugar recovery, fertiliser usage, irrigation, cane burning and power export. A factory set up efficiently for maximum power generation can show a negative carbon footprint and, in this respect, maximum export of electric power can deliver a lower carbon footprint than maximum ethanol production. The calculation routine estimates the greenhouse gas emissions from field to factory gate and can be used for an existing operation or in the design of a new project to assist in making good sustainability choices.

Introduction

The issue of climate change has promoted an interest in the greenhouse gas (GHG) emissions, otherwise referred to as the carbon footprint, associated with a variety of products. The main focus has been on the production of biofuels, which has spurred the development of systems to estimate GHG emissions. Pressure is coming from the market place, through consumer expectations, and from responsible producers, to measure, control and minimise the carbon footprint of their products.

The carbon footprint of cane sugar is favourably impacted by the use of the natural fibre in sugarcane, which provides the fuel source for its production. The development of a system of calculating emissions that has wide acceptance is an important step in being able to measure and then control emissions.

It is impossible to control emissions until they are first measured. This becomes a powerful tool in the hands of producers, enabling them to assess how changes in the way they produce sugar can influence GHG emissions and one that serves as a basis for sound decision-making by business, consumers and other stakeholders.
Emissions are an important aspect of the broader subject of sustainable production. This paper focuses on the method used to estimate emissions in the production of raw sugar, and was developed as part of the sustainability standards of the Better Sugarcane Initiative.

**Status of efforts to calculate carbon emissions**

The major impetus for the calculation of carbon emissions has been the production of biofuels and the conditions which the EU and other importers wish to attach to imported biofuels, largely in an attempt to ensure that they are produced in a sustainable way. Sugarcane is the source of a great deal of ethanol produced, mainly in Brazil, and increasingly to a larger extent in other cane producing countries.

Thus, a number of studies have been done to estimate the net energy ratios and carbon emissions associated with bioethanol production. Different estimates of GHG emission savings relative to fossil fuels are obtained if different assumptions are made in the calculation procedure.

Wang *et al.* (2008) estimate a reduction of 78% for ethanol transported to the US from Brazil; they estimate this will increase by up to 9 percentage points if cane burning is phased out. Data produced in Brazil indicates that bioethanol produced and used in Brazil shows GHG emissions savings of 89% compared with petrol (BNDES, 2008).

The EU has compiled a Renewable Energy Directive (RED) which sets out how the emissions should be calculated for the production of a biofuel from any particular feedstock. In addition, some GHG emission saving default values, assuming no land use change, are given to be used in the absence of primary data required for its calculation.

Ethanol produced from sugarcane has the best default value of 71% emission saving relative to fossil fuels; emission savings using corn, wheat or sugar beet are significantly lower, varying between 16 and 52% depending on the feedstock and the process used.

The carbon footprint of sugar has received less attention. PAS 2050:2008 is a Publicly Available Specification, developed in the UK in conjunction with the Carbon Trust (BSI, 2008).

Recently, both British Sugar Corporation and Tate & Lyle have used this carbon footprint and labelling initiative to evaluate the carbon footprint of sugar, using a life cycle analysis approach. Renouf and Wegener (2007) have calculated the carbon footprint for raw sugar production under three different Queensland scenarios.

In the US, there has been controversy surrounding the net energy ratio and the GHG emissions for ethanol for use as automobile fuel produced from corn, relative to gasoline. The results of a number of studies have illustrated clearly how the input assumptions can radically affect the estimated quantities.

Various studies on the net energy value of ethanol from corn have been compared by Farrell and co-workers at UC Berkeley (Farrell *et al.*, 2006). Their EBAMM (ERG Biofuels Analysis Meta-Model) spreadsheets are available on the internet and are used as the basis for the computations here.

A number of other carbon calculators are available on the internet, mostly designed for the production of biofuels, which also take into account the distribution and use of the biofuels. The Renewable Fuels Agency in the UK provides an on-line calculator, as does the GREET (Greenhouse Gases, Regulated Emissions and Energy Use in Transport) model produced by the Argonne National Laboratory in the US (Wang *et al.*, 2008). This list is not exhaustive and various other calculators are available from specialist consultants.

**System boundary**

In conducting life cycle analyses, it is important to define the boundary of the system under investigation. The scope of the system being investigated has a substantial effect on the computations. In the case of sugarcane, the best approach considers the system to contain each individual mill and its growers as a unit, rather than a company owning and operating more than
one mill. In the case of IPPs (Independent Power Producers) providing steam and power to a mill from bagasse that has been provided by the mill, the IPP should be considered together with the mill concerned. All the activities of a plant on one site should be considered, to reflect the sustainability of the total system producing food, fuel, energy and chemicals.

The system boundary includes growing and processing of sugarcane, but also includes embedded energy inputs. It starts with the manufacture of fertiliser and chemicals. Farming operations include chemicals application, irrigation, tillage and harvesting.

The cane is processed to sugar and molasses or ethanol, and may include export of electric power or bagasse. No allowance for transport of products from the factory is allowed for. The system is illustrated in Figure 1.

![System boundary assumed for GHG emissions calculation.](image)

There are two commonly used descriptions for life cycle analyses, Business-to-Business (B2B) and Business-to-Consumer (B2C). The former accounts for the provision of inputs, including products, to a third party that is not the end user (cradle-to-gate); the latter accounts for the provision of inputs, including products, to the end user (cradle-to-grave), thus including the packaging and transport of products to the retailer/consumer, as well as the recycling and disposal of packaging waste.

This analysis represents a B2B analysis, considering the operation of a cane sugar processing facility, producing raw sugar and/or ethanol at the factory gate.

**Direct and indirect effects**

The energy and GHG calculations are associated with direct energy inputs and at a second level by indirect inputs.

Direct inputs are mainly fuel and power inputs, expressed in terms of the primary energy value (taking into account e.g. the efficiency of conversion of fuel to power, and the energy in producing gasoline and diesel). Indirect inputs include, in addition, the energy required for the production of chemicals, fertilisers and other materials used.

In some cases the indirect inputs also include the additional energy necessary for the manufacture and construction of farm, transport and industrial equipment and buildings. There is as yet no uniformity in different approaches.

PAS 2050 (BSI, 2008) dictates that the GHG emissions arising from the production of capital goods used in the life cycle of the product should be excluded from the assessment of the GHG emissions of the life cycle of the product. This is also the approach taken by Concawe (2007), the RTFO in the UK and the EU RED. American approaches tend to include this energy; in this analysis, it is excluded.
Land use change

It has been suggested that land use changes due to large scale sugarcane expansion could lead to significant changes in the soil carbon. This could result in additional emissions by sacrificing carbon storage and sequestration as land is diverted from its existing uses. These changes can be separated into direct and indirect components:

- **Direct** land change refers to a change from the original state of the land to use for sugarcane production. Depending on the previous use of the land in question, it is surmised that the land use change can unlock some of the carbon in the existing soil and vegetation.

- **Indirect** land use change concerns secondary effects induced by large scale expansion. This displaces existing crops, leading to expansion of crop land elsewhere, either in the same country or in other parts of the world. The effects of these changes are very difficult to estimate, and have generally been neglected in any analyses, largely because of the uncertainty in modelling the effects.

Searchinger et al. (2008) postulated that taking account of both direct and indirect land use change will make most biofuel ventures GHG positive, rather than reducing GHG emissions. This is based on the assumption that, as biofuel crops displace other crops, commodity prices rise and new land is put to crop cultivation in various countries, particularly Brazil, China, India and the US. Their results have been disputed by a number of people; for example, Kim et al. (2009) suggest that sustainable crop management practices significantly reduce the direct land use effect, while indirect land usage estimates are too uncertain to have any validity, depending substantially on what assumptions are made.

The Gallagher report prepared for the UK government released in 2008 concludes that GHG emission estimates must include the effects of indirect land use change and also avoided land use from co-products. The report recommends that biofuel production should target only idle and marginal land and make more use of wastes and residues. It also calls for sustainability standards to be extended beyond biofuels to all agricultural production.

The EU RED allows for a substantial credit of 29 g CO$_2$eq/MJ for a period of 10 years if severely degraded or contaminated land is used for biofuel crop purposes. Klenk and Kunz (2008) have shown that, in the case of ethanol production from sugar beet and wheat, the co-products replace other feedstuffs which would have required additional land, and so actually free up land for other crop production. In some developing nations, the land can actually be improved by diligent farming.

Because the methods and data requirements for calculating emissions from indirect land use change are not fully developed, the assessment of emissions arising from indirect land use change is not included in any current estimation procedures, but this is likely to change in the future.

In general it is accepted that direct land use change after a cut-off date must be taken into account. The PAS 2050 standard proposes a cut-off date of 1 January 1990, but the EU RED suggests 1 January 2008. In the absence of better information, the table of IPCC default land use change values for selected countries published in the PAS 2050 can be used (BSI, 2008). For perennial cropland, the default values are of the order of 15 to 25 t CO$_2$eq/(ha.y) for conversion of forest land and 1.5 to 7 t CO$_2$eq/(ha.y) for grassland. The values for forest land conversion are punitive and sufficient to derail development of new cane estates.

**Handling of co-products and multiple products**

A co-product is any one of two or more products, where one cannot be produced without the other being produced. An example is molasses, which is not produced unless sugar is produced at the same time. Sugar and ethanol produced in a mill would be regarded as multiple products. Waste products are defined by the IPCC as having no economic value, and will have zero allocation of energy and emissions.
Different methods of handling co-product credit have been suggested. The Concawe report (Concawe, 2007) as well as ISO 14044 lifecycle assessment standards favour the ‘substitution’ or ‘displacement’ method, which attempts to model reality by tracking the likely fate of by-products. Each co-product generates an energy and emission credit equal to the energy and emissions saved by not producing the material that the co-product is most likely to displace. Other studies have used ‘allocation’ methods whereby energy and emissions from a process are allocated to the various products according to mass or energy content or monetary value. These allocation methods are attractive because they are simpler to use, but they have little logical or physical basis, and allocation on monetary value varies by region and over time. In the event that substitution is not feasible, ISO 14044 standards recommend allocation by economic value. Although the prices may change over time, the relative market prices between joint products may be less subject to variation than absolute prices.

The displacement method has been favoured in the US in determining the credit to be applied to co-products, particularly DDGS (Farrell et al., 2006; Gabroski, 2002). In the case of corn ethanol, sensitivity analysis has shown that co-product allocation has the greatest individual effect on calculations.

In the case of sugarcane processing, a factory exporting power or bagasse can apply a credit in terms of energy and emissions saved. Thus, the use of the term ‘GHG emissions’ actually refers to ‘net GHG emissions’ after applying a credit for energy exports. Wang et al. (2008) assume that electricity exported by the mill displaces electricity generated with natural-gas electric power plants. This is contrary to PAS 2050 which dictates displacement of energy with the country’s average generation mix.

In terms of efficiency, cogeneration is intrinsically superior to conventional power generation. Conventional technologies convert into useful power about 30% – and in extreme conditions up to 50% – of the energy in the fuel. Cogeneration systems, by directing otherwise wasted heat to meet thermal needs of the process, achieve efficiencies exploiting 85% of the fuel’s efficiency (BNDES, 2008). Potentially, using 50% of the cane tops and leaves, generating steam at 105 bar and 525°C, should enable the year-round export of 158 kWh/t cane processed. A process for gasification could increase power generation to yield above 180 kWh/t cane processed.

Where a factory produces only sugar and molasses, the allocation in proportion to market value is most easily adopted; in most cases, the allocation to molasses is less than 10% of the total and the products it displaces (e.g. animal feed components) may be difficult to identify in different countries.

In the case of a factory producing more or less equivalent quantities of sugar and ethanol, the split of energy input and GHG emissions between the two products becomes a more difficult issue. The EU RED requires that allocation should be by energy content of the products. Sugar has a calorific value of 16 500 MJ/t and ethanol 21 MJ/L; on the basis that 600 L of ethanol are produced from one tonne of sucrose, this implies an ethanol equivalent value of 16 500/600 = 27.5 MJ/L for sucrose. On this basis, 57% of the emissions should be allocated to sugar and 43% to ethanol.

In the case of an autonomous distillery, where the only product is ethanol, the problem disappears, and energy use and emissions are related to litres of ethanol produced.

Assumptions and methodologies involved

Components contributing to emissions

CO₂ from sugarcane emitted in combustion and in ethanol fermentation is considered zero CO₂ emission to the air, because this is the carbon taken in from the air during sugarcane growth. CO and VOCs emitted in combustion are assumed to be converted to CO₂ fairly rapidly, but methane and nitrous oxide (N₂O) from burning bagasse must be accounted for in GHG emissions.
CO₂ emissions arising from biogenic carbon sources are excluded from the calculation of GHG emissions from the life cycle of products, except where the CO₂ arises from direct land use change.

The greenhouse gases covered in the Kyoto protocol are CO₂, N₂O, CH₄, SF₆, methylene chloride, certain ethers, perfluorinated compounds and hydrofluorocarbons. Only the first three are relevant here. Methane and N₂O have global warming potentials 25 and 298 times that of CO₂ respectively (IPCC, 2007). The carbon equivalent value is calculated by multiplying the mass of one of these gases by its global warming potential. This is added to the CO₂ evolved and expressed as CO₂ equivalent (CO₂eq).

Methane produced in anaerobic digesters that is used as fuel in boilers is not considered to produce GHG emissions. Methane produced by anaerobic processes from wastes but not captured has to be taken into account in calculating emissions. Where methane is combusted without the generation of useful energy (i.e. flaring), no GHG emissions shall be incurred where the methane being combusted is derived from the biogenic component of the waste.

**Default and secondary data**

In some cases, secondary data (obtained from sources other than direct measurement) may be used to calculate emissions in preference to primary data to enable consistency and, where possible, comparability. Generally used secondary data used here are:

- Global warming potential of greenhouse gases
- Electricity emissions (in kg CO₂eq/kWh) from various energy sources
- Energy content of fertilisers per kg
- Energy use of pesticides and herbicides per kg
- Embedded energy and emissions for process chemicals
- Fuel emissions per litre
- Waste emissions per kg
- N₂O and CH₄ emissions from burning bagasse
- N₂O and CH₄ emissions from burning cane
- Direct land use change
- Agriculture emissions from soils

Default values used have been collected from a number of sources and are given in the Appendix. The EU RED suggests a more detailed treatment of default values which can give more accurate results where the particular type of nitrogenous fertiliser is specified.

**Calculation method**

The calculation approach adopted in this study is similar to that used in the EBAMM model, which itself is similar to the GREET model. These models have been used mainly to model the production of biofuels from corn, and they have had to be modified for sugarcane to incorporate additional issues as follows:

1. Modifications to incorporate sugar manufacture as the major activity. This includes power, fuels and lubricants.
2. Emissions due to cane burning. This is based on IPCC emission factors for burning biomass of 0.07 kg N₂O/t dry matter and 2.7 kg CH₄/t dry matter.
3. Allowance for N₂O emissions from filter cake, vinasse and cane residue left in the field. This assumes 1.225% of N in the residue is converted to N in N₂O (Macedo et al., 2008).
4. Emissions of CH₄ and N₂O in burning bagasse in sugar mill boilers; values of 30 and 4 g/1000 MJ energy in bagasse respectively are used (Wang et al., 2008).
5. Energy value of process chemicals.
6. A credit for molasses (where produced) based on its economic value relative to that of sugar.

7. Emissions from anaerobic treatment of effluent in the case that methane is not captured and used as a fuel. IPCC guidelines suggest 0.21 t CH₄ produced per t COD removed.

8. Allowance for any imports of molasses, bagasse and/or other biomass.

Difficulties associated with agricultural chemicals

The GHG balance is particularly uncertain because of nitrous oxide emissions. N₂O emissions can vary by more than two orders of magnitude, depending on a complex combination of soil composition, climate, crop and farming practices.

The use of nitrogen fertilisers results in GHG emissions in two stages: fertiliser manufacture (primarily CO₂ emissions from energy used) and fertiliser application (primarily N₂O emissions from nitrification and denitrification processes in the soil).

The assumption is made that 1.325% of N in nitrogen fertiliser is converted to N in N₂O through nitrification and denitrification, following the IPCC recommendations.

Various studies in Australia have focussed on GHG emissions, and how they are affected by soil type, moisture conditions and trash blanketing (Allen et al., 2008; Denmead et al., 2008; Denmead et al., 2005).

These studies estimated that N₂O emissions from Australian sugarcane soils may be higher and more variable than the emission factor of 1.325% recommended by the IPCC. Wang et al. (2008), however, showed that, for conditions approximating average conditions in Queensland, the emissions factor is close to the IPCC value.

Agricultural lime application results in GHG emissions from both production energy use and in-soil reactions that release CO₂. These latter emissions are poorly understood and are a source of uncertainty. The EBAMM model uses the IPCC factor of 0.44 kg CO₂eq/kg lime, which assumes that all C in lime becomes CO₂. This is the upper limit; it is possible in weakly acidic soils that limestone results in a net sink of CO₂.

Calculation results

A typical sugar mill has been modelled, based on processing 500 tonnes cane/hour and producing only sugar and molasses. The average values for the base case considered are shown in Table 1.

This assumes a conventional mill producing only sugar and molasses, processing 50% burnt cane, with some power imported for use in irrigation and some exported.

The results are summarised in Table 2. Net energy use in the agricultural operation is 206 MJ/tC (MJ/tonne cane) and in cane transport 26 MJ/tC. The combined number of 232 MJ/tC is slightly higher than the comparable value calculated for Brazil centre-south conditions of 210 MJ/tC.

The total energy usage of 278 MJ/tC is reduced by the export of power, to give a net energy usage of 98 MJ/tC. This is a substantial reduction, largely due to the multiplier for exported power of 2.5 to convert the exported power to its primary energy value, based on an average conversion efficiency of primary energy to power of 40%.

An average emissions factor of 150 g CO₂eq/MJ for electricity production is assumed; in practice, the value relevant to the country considered would need to be used.

The total GHG emissions are 0.43 g/g sugar, but when the credit for molasses production and power export is applied, this drops to 0.31 g CO₂eq/g sugar. In this instance, with the relative prices for sugar and molasses used, 7% of the GHG emissions are allocated to molasses. The emissions associated with molasses are < 0.1 g CO₂eq/g molasses.

A breakdown of the energy usage and GHG emissions is illustrated in Figures 2 and 3.
Table 1—Input data for base case net energy usage and GHG emissions calculations.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane processed</td>
<td>2 000 000 t cane / y</td>
</tr>
<tr>
<td>Crop yield – cane harvested</td>
<td>80.0 t cane / ha</td>
</tr>
<tr>
<td>Average cane age at harvest</td>
<td>12 months</td>
</tr>
<tr>
<td>Processing hours / y</td>
<td>4000 h</td>
</tr>
<tr>
<td>Sugar production / y</td>
<td>222 222 t sugar</td>
</tr>
<tr>
<td>Molasses % cane</td>
<td>3.5 t/100 t cane</td>
</tr>
<tr>
<td>Prices / t sugar</td>
<td>$330</td>
</tr>
<tr>
<td>Prices / t molasses</td>
<td>$80</td>
</tr>
<tr>
<td>Cane / seed cane</td>
<td>7.0 ha cane/ha seed</td>
</tr>
<tr>
<td>N Application rate, as elemental N</td>
<td>75.0 kg/ha</td>
</tr>
<tr>
<td>P₂O₅ application</td>
<td>75.0 kg/ha</td>
</tr>
<tr>
<td>K₂O application</td>
<td>75.0 kg/ha</td>
</tr>
<tr>
<td>Lime application</td>
<td>1000.0 kg/ha</td>
</tr>
<tr>
<td>Herbicide application rate</td>
<td>2.2 kg/ha</td>
</tr>
<tr>
<td>Insecticide</td>
<td>0.16 kg/ha</td>
</tr>
<tr>
<td>Diesel used in agriculture</td>
<td>100 L/ha</td>
</tr>
<tr>
<td>Electric power</td>
<td>90 kWh/ha</td>
</tr>
<tr>
<td>Electric power used in irrigation</td>
<td>450 kWh/ha</td>
</tr>
<tr>
<td>Cane Burnt</td>
<td>50 %</td>
</tr>
<tr>
<td>EM in cane (50 % moisture)</td>
<td>8 t/100 t cane</td>
</tr>
<tr>
<td>Total EM (Extraneous Matter)</td>
<td>140 kg DM/tC</td>
</tr>
<tr>
<td>Average cane transport distance (1 way)</td>
<td>10 km</td>
</tr>
<tr>
<td>Average payload</td>
<td>20 t cane</td>
</tr>
<tr>
<td>Average diesel consumption</td>
<td>1.7 km/L</td>
</tr>
<tr>
<td>Filter cake produced</td>
<td>5 t/100 t cane</td>
</tr>
<tr>
<td>Factory lime usage</td>
<td>0.7 g/tC</td>
</tr>
<tr>
<td>Caustic soda used</td>
<td>100 g/tC</td>
</tr>
<tr>
<td>Make-up process water</td>
<td>10 L/tC</td>
</tr>
<tr>
<td>Boiler feed water chemicals used</td>
<td>100 g/tC</td>
</tr>
<tr>
<td>Biocide enzymes and flocculants used</td>
<td>18 g/tC</td>
</tr>
<tr>
<td>Bagasse burned</td>
<td>0.29 t/tC</td>
</tr>
<tr>
<td>Bagasse LCV</td>
<td>7315 MJ/tC</td>
</tr>
<tr>
<td>Average power exported</td>
<td>10 MW</td>
</tr>
<tr>
<td>Electric power imported</td>
<td>0.3 kWh/tC</td>
</tr>
<tr>
<td>Factory coal consumption</td>
<td>1.0 kg coal/tC</td>
</tr>
</tbody>
</table>

Table 2—Summary of energy and emission calculation results.

<table>
<thead>
<tr>
<th></th>
<th>Net energy usage (MJ)</th>
<th>GHG emissions (kg CO₂eq)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>per t cane</td>
<td>per t sugar</td>
</tr>
<tr>
<td>Total agricultural phase</td>
<td>206</td>
<td>34.3</td>
</tr>
<tr>
<td>Transportation of cane</td>
<td>26</td>
<td>2.4</td>
</tr>
<tr>
<td>Processing</td>
<td>46</td>
<td>417</td>
</tr>
<tr>
<td>Total production</td>
<td>278</td>
<td>2 505</td>
</tr>
<tr>
<td>Power exported</td>
<td>180</td>
<td></td>
</tr>
<tr>
<td>Processing production net</td>
<td>–134</td>
<td></td>
</tr>
<tr>
<td>Total production net</td>
<td>98</td>
<td>885</td>
</tr>
<tr>
<td>Allocation to molasses</td>
<td>7</td>
<td>199*</td>
</tr>
<tr>
<td>Allocation to sugar</td>
<td>822</td>
<td></td>
</tr>
</tbody>
</table>

*per tonne molasses
Emissions from the use of nitrogen fertilisers and lime in the fields account for almost half the emissions from the agricultural operations. The uncertainty introduced by the use of these fertilisers has a significant bearing on the reliability of the emissions estimates. Burning of cane in the fields also has a significant effect, comprising 10 to 15% of agricultural emissions when the total crop is burnt.

These values assume that all sugarcane lands were established before the cut-off date, thus excluding direct land change effects. The effect of direct land use change is very significant. If it is assumed that all cane land is established from grassland, use of the average of IPCC default values of 4 t CO₂eq/(ha.y) leads to doubling of the carbon footprint, before any credits, to 0.86 g CO₂eq/g sugar.

After credits for molasses and power, the footprint at 0.73 g CO₂eq/g sugar is more than double that of the base case. If it is forest land that is converted, the penalty in terms of GHG emissions is too large to bear.
Sensitivity to input parameters

A sensitivity analysis was carried out to show the effect of changes in the assumptions that have the greatest effect on the calculated values. This is a simplified analysis, since it assumes that changing one variable at a time does not affect any other variables. Impacts of the most important variables are shown in Table 3. It is apparent that the yield of cane per ha and the recovery of sugar in the mill (cane/sugar ratio) both have a substantial effect. The cane transport has a less significant effect on GHG emissions. The quantities of N fertiliser and lime added also have a considerable influence. The effect of emissions in the field is known to be uncertain and variable and so could be responsible for considerable uncertainty in the values obtained. The extent of cane burning is also very significant; it leads to significant amounts of CH₄ and N₂O emissions, with a high global warming potential. Cane residues left to rot in the fields lead to much lower GHG emissions.

Table 3—Effect of changes in major variables on energy usage and GHG emissions.

<table>
<thead>
<tr>
<th>Parameter varied from base case:</th>
<th>Energy usage (MJ)</th>
<th>GHG emissions (CO₂eq)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Agric. MJ/tC</td>
<td>Process MJ/tC</td>
</tr>
<tr>
<td>Base case</td>
<td>206.1</td>
<td>46.4</td>
</tr>
<tr>
<td>Parameter varied from base case:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cane yield 50 t/ha</td>
<td>329.8</td>
<td>46.4</td>
</tr>
<tr>
<td>Cane yield 120 t/ha</td>
<td>137.4</td>
<td>46.4</td>
</tr>
<tr>
<td>Cane/sugar 7</td>
<td>206.1</td>
<td>46.4</td>
</tr>
<tr>
<td>Cane/sugar 11</td>
<td>206.1</td>
<td>46.4</td>
</tr>
<tr>
<td>N fertiliser 30 kg/ha</td>
<td>173.7</td>
<td>46.4</td>
</tr>
<tr>
<td>N fertiliser 150 kg/ha</td>
<td>260.1</td>
<td>46.4</td>
</tr>
<tr>
<td>Lime use 0 t/ha</td>
<td>196.6</td>
<td>46.4</td>
</tr>
<tr>
<td>Lime use 2 t/ha</td>
<td>215.7</td>
<td>46.4</td>
</tr>
<tr>
<td>Irrigation 0 kWh/ha</td>
<td>155.5</td>
<td>46.4</td>
</tr>
<tr>
<td>Irrigation 900 kWh/ha</td>
<td>256.8</td>
<td>46.4</td>
</tr>
<tr>
<td>Cane burnt 0%</td>
<td>206.1</td>
<td>46.4</td>
</tr>
<tr>
<td>Cane burnt 100%</td>
<td>206.1</td>
<td>46.4</td>
</tr>
<tr>
<td>Power export 0 MW</td>
<td>206.1</td>
<td>46.4</td>
</tr>
<tr>
<td>Power export 40 MW</td>
<td>206.1</td>
<td>46.4</td>
</tr>
<tr>
<td>Cane transport 0.5 × base</td>
<td>206.1</td>
<td>45.7</td>
</tr>
<tr>
<td>Cane transport 2 × base</td>
<td>206.1</td>
<td>47.7</td>
</tr>
</tbody>
</table>

The major influence on energy and GHG emissions is the extent of power export. The base case assumes that 10 MW is exported on average during the crushing season, representing 20 kWh/tC in this case. Reducing this to zero increases the net GHG emissions by about one third. Conversely, if the export is increased to over 80 kWh/tC, the GHG emissions actually become negative. This does not mean that the system is actually abstracting CO₂ from the atmosphere, but rather that the effect of power replaced gives a negative balance. A negative net energy use is also obtained.

The use of sulfitation, with a high dosage of 500 g S/tC, has a small effect, only increasing the emissions figure by 0.02 g CO₂eq/g sugar.

If the energy embedded in capital plant and equipment is included, as some schemes propose, the overall effect is small. The net energy usage increases by about 50 kW/tC, but the GHG emissions increase by only 0.02 g CO₂eq/g sugar.
If the blackstrap molasses produced is all converted to ethanol (18.2 ML/y), the GHG emissions are little changed. If they are allocated to sugar and ethanol according to the energy value of the products, the emissions factor for sugar reduces to 0.29 g CO$_2$eq/g sugar, and the emissions for ethanol are 388 g CO$_2$eq/L or 18.3 g CO$_2$eq/MJ.

If ethanol only is produced, the net energy used increases to 118 kW/tc or 1.5 MJ/L ethanol. Carbon emissions are 488 g CO$_2$eq/L ethanol or 23.0 g CO$_2$eq/MJ. This compares with estimates for the Brazilian centre south region of 417 and 436 kg CO$_2$eq / m$^3$ of ethanol for hydrous and anhydrous ethanol respectively, or 20 g CO$_2$eq/MJ (Macedo et al., 2008).

Results of other studies

Tate & Lyle report a figure for white cane sugar of 0.38 g CO$_2$eq / g sugar in a 1 kg consumer pack. Previously, they had reported a value of 0.5 g CO$_2$eq / g sugar, taking into account refining, packing and transport, and recycling and disposing of packaging waste (Houghton-Dodd, 2008).

The growing and milling activities are responsible for 0.19 g CO$_2$eq / g sugar. The figure reported by Tate & Lyle for beet sugar in the same study is almost 1 g CO$_2$eq / g sugar.

Renouf and Wegener (2007) report much higher values in the range of 0.5 to 0.8 g CO$_2$eq / g sugar. These values are inflated by higher estimates of nitrogen emissions from fertiliser, by irrigation and emissions from energy embedded in agricultural capital equipment.

Florida Crystals market ‘carbon-free’ sugar, achieved through the cogeneration and sale of electric power. Their power generation facility can produce 80 MW from 103 bar steam, using the mill bagasse as well as 900 000 tonnes of wood waste/year diverted from landfills as the fuel source.

British Sugar used the procedure of PAS 2050 to arrive at a figure of 0.6 g CO$_2$eq / g sugar. This is the B2B figure, as provided to the industrial user. About 60% of the emissions are due to fuel use at the factory (pers. comm. P. Watson 2009).

Use of cogeneration in the manufacture of ethanol from wheat particularly in combination with a gas-fired turbine can significantly improve energy and emission improvements relative to gasoline (Concawe, 2007). This strategy is put to good use in British Sugar’s operations.

Strategies to reduce carbon emissions

Any strategy to reduce overall energy use, minimise the use of raw materials and other inputs, and reduce waste will lead to a reduction in the carbon footprint. It seems, therefore, that a low carbon footprint will generally be a consequence of an efficient operation.

In the sugarcane industry, particular improvements can be achieved by focussing on the following, in roughly the following order of importance:

- Cogenerate and export power to the maximum extent possible
- Maximise cane yield and factory recovery
- Reduce the amount of fertiliser and chemical inputs, particularly N fertiliser
- Reduce the extent of cane burning to zero
- Reduce the quantities of any supplementary fuels purchased.
- Minimise irrigation power input.
- Reduce cane transport distances
- Recycle water to reduce water intake.

Other avenues to explore could involve the generation of biogas from wastes. Vinasse from 1 m$^3$ of ethanol treated anaerobically produces 115 m$^3$ of biogas, which in turn can generate 169 kWh of power, after deducting the power used in the process (BNDES, 2008). This can help to augment the amount of power available for export.
Conclusions

It is anticipated that, in the future, the carbon footprint associated with the production of sugar in any cane growing area of the world will have to be declared. This paper provides a way to do this, using currently accepted practices. It is an objective of the Better Sugarcane Initiative to get agreement on a standardised system of estimation both within the sugar industry and the international consumer markets.

The carbon footprint of sugar at the factory gate is expected to be about 0.3 g CO$_2$eq/g sugar on average. In a country where the average per capita consumption is 30 kg sugar per annum, the emissions from the consumption of sugar will be 10 kg CO$_2$ per capita per year. In the UK, the average individual carbon footprint is about 11 t/year – clearly sugar consumption plays a minuscule part in an individual’s carbon footprint.

The carbon footprint of sugar is low by comparison with other products, particularly when full use is made of energy production in conjunction with sugar. This can be used to promote the use of sugar, particularly by comparison with other sweeteners.

REFERENCES


APPENDIX

DEFAULT VALUES USED

Most of the default values are obtained from the EBAMM model (Farrell et al., 2006), often based on the GREET model using data from Shapouri et al. (2004) and Graboski (2002), or from Macedo et al. (2008).

Fertiliser and agricultural chemicals, in MJ/kg:

<table>
<thead>
<tr>
<th></th>
<th>Energy demand (MJ/kg)</th>
<th>Emissions factor (kg CO₂eq/kg)</th>
<th>Emissions on application (kg CO₂eq/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (elemental)</td>
<td>56.9</td>
<td>4.0</td>
<td>6.2</td>
</tr>
<tr>
<td>Potash (K₂O)</td>
<td>7.0</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>Phosphate (P₂O₅)</td>
<td>9.3</td>
<td>0.71</td>
<td></td>
</tr>
<tr>
<td>Lime (CaCO₃)</td>
<td>0.12</td>
<td>0.07</td>
<td>0.44</td>
</tr>
<tr>
<td>Herbicide</td>
<td>355.6</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Insecticide</td>
<td>358</td>
<td>29</td>
<td></td>
</tr>
</tbody>
</table>

Data from EBAMM

Primary energy inputs and emissions:

<table>
<thead>
<tr>
<th></th>
<th>Energy Demand (MJ/MJ fuel)</th>
<th>Total emissions (g CO₂eq/MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>1.14</td>
<td>85</td>
</tr>
<tr>
<td>Diesel</td>
<td>1.16</td>
<td>91</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>1.24</td>
<td>96</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>1.12</td>
<td>66</td>
</tr>
<tr>
<td>Coal</td>
<td>1.00</td>
<td>107</td>
</tr>
<tr>
<td>Electricity</td>
<td>2.5</td>
<td>150*</td>
</tr>
</tbody>
</table>

Energy demand data from Macedo et al. (2008), emissions from EBAMM

*Average value; country specific values should be used.

The energy value is multiplied by the energy demand factor to give the primary energy value.
Embedded energy and emissions for process chemicals:

<table>
<thead>
<tr>
<th></th>
<th>Energy demand (MJ/kg)</th>
<th>Emissions factor (g CO₂eq/MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime (CaO)</td>
<td>0.1\textsuperscript{1}</td>
<td>95\textsuperscript{1}</td>
</tr>
<tr>
<td>Biocide</td>
<td>3.0\textsuperscript{2}</td>
<td>95\textsuperscript{1}</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>56.3\textsuperscript{3}</td>
<td>95\textsuperscript{1}</td>
</tr>
<tr>
<td>Caustic</td>
<td>75</td>
<td>95\textsuperscript{1}</td>
</tr>
<tr>
<td>Sulfuric acid</td>
<td>2.4</td>
<td>95\textsuperscript{1}</td>
</tr>
<tr>
<td>Anti-foam</td>
<td>10</td>
<td>95\textsuperscript{1}</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>50</td>
<td>95\textsuperscript{1}</td>
</tr>
</tbody>
</table>

\textsuperscript{1} Macedo et al. (2008); \textsuperscript{2} Mortimer et al. (2004); \textsuperscript{3} EBAMM

L’EMPREINTE CARBONE DU SUCRE

Par

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MOTS-CLES: Empreinte Carbone, Énergie, Canne à Sucre, Sucre, Éthanol.

Résumé

Le changement climatique est à devenir rapidement un problème grave qui exigera de plus en plus l’attention des producteurs de sucre. Estimer les émissions de gaz à effet de serre dans la production de sucre, aussi connu comme l’empreinte carbone, est une partie essentielle de toute étude de durabilité. Une méthode d’estimation de l’utilisation net d’énergie et des émissions de gaz à effet de serre a été développée, basée sur les travaux effectués sur les biocarburants. Le calcul habituel a été développé pour être utilisé dans les normes de la Meilleure Initiative de la Canne à Sucre, qui mettent l’accent sur la durabilité de l’industrie sucrière. Ce calcul estime les besoins en énergie primaire y compris les effets directs, principalement la consommation de l’énergie, et les effets indirects, qui comprennent l’énergie utilisée dans la production de combustibles, d’engrais et de produits chimiques. Il prévoit également les effets sur le changement d’utilisation des terres. La méthode d’estimation comprend la production de mélasse et/ou d’éthanol et l’exportation de l’énergie. Les erreurs potentielles et les problèmes rencontrés pour arriver à ces estimations sont pris en compte. Les principaux problèmes sont les incertitudes liées aux émissions de l’utilisation d’engrais et la façon dont les émissions sont allouées pour les coproduits. Les résultats démontrent que l’empreinte carbone est plus affectée par le rendement de canne, la récupération du sucre, l’utilisation des engrais, l’irrigation, le brûlis de la canne et l’exportation de l’énergie. Une usine efficiente, configuré pour un maximum de production d’énergie, peut montrer une empreinte carbone négative et, à cet égard, l’exportation d’énergie électrique maximale peut montrer une empreinte carbone inférieure à la production d’éthanol maximale. Le calcul habituel des émissions de gaz à effet de serre des champs à l’usine peut être utilisé pour une unité existante ou dans la conception d’un nouveau projet pour aider à faire les bons choix durables.
LA HUELLA DE CARBÓN DEL AZÚCAR

Por

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PALABRAS CLAVE: Huella de Carbón, Energía, Caña de Azúcar, Azúcar, Etanol.

Resumen

El cambio climático se ha convertido en un tema muy serio y requerirá cada vez más de la atención de los productores de azúcar. Estimar las emisiones de gases del efecto invernadero en la producción de azúcar, conocida también como la huella de carbono, es una parte esencial de cualquier estudio de sostenibilidad. Se ha desarrollado un método para estimar el uso neto de energía y las emisiones de gases de invernadero, basado inicialmente en trabajos anteriores realizados en bio combustibles. La rutina de cálculo fue desarrollada para ser usada en los estándares de la Iniciativa para Mejor Azúcar (Better Sugarcane Initiative, Reino Unido, en inglés) la cual se enfoca en la sostenibilidad de la industria de la caña de azúcar. Este procedimiento de cálculo estima los requerimientos de energía primarios, incluyendo tanto los efectos directos como el uso de energía y los indirectos como la energía empleada en la producción de combustibles, fertilizantes y productos químicos. También se pueden incluir los efectos de los cambios provocados por el uso directo de la tierra. Este procedimiento de cálculo también incluye la producción de melazas y/o etanol y la exportación de energía. Se ha prestado atención a los errores potenciales y a los problemas que se deriven de llegar a estos estimados. Los principales problemas son las incertidumbres de las emisiones derivadas del uso de fertilizantes y la forma en que las emisiones son adjudicadas a los co-productos. Los resultados muestran que la huella de carbón está afectada en mayor proporción por el rendimiento de azúcar, la recuperación de azúcar, el uso de fertilizantes, el riego, la quema y la exportación de energía. Una fábrica planificada para obtener máxima eficiencia en la generación de energía puede mostrar una huella de carbón negativa y a este respecto, la mayor exportación de energía puede derivar en una huella de carbón más baja que la producción de alcohol más eficiente. La rutina de cálculo estima las emisiones de gases del efecto invernadero desde el campo hasta las puertas de la fábrica y puede ser usada para una operación existente o en el diseño de un proyecto nuevo para la adecuada toma de decisiones que garanticen la sostenibilidad del mismo.
RADICAL NEW RESEARCH STRATEGY AT THE SMRI: SOME LEARNINGS FROM THE PREPEX PROJECT

By

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KEYWORDS: Prepex, Research, Commercialisation, Patenting.

Abstract

In 2006, the Sugar Milling Research Institute (SMRI) embarked upon an ambitious new research strategy to develop technologies capable of creating step-change opportunities for the South African sugarcane processing industry. In doing this, the SMRI has moved away from incremental improvements to much more innovative research with potentially greater commercial rewards for its members. The first major project to be identified under this new strategy was the ‘Prepex’ project, which aims to replace the conventional cane preparation equipment with non-wearing components in order to minimise downtime for knife and hammer replacement. Laboratory and small-scale pilot plant research was undertaken, a detailed economic model was developed, and market assessment was conducted to assess the technical and commercial viability of the process. The technology was proven and a patent was lodged. The learnings outlined in this paper include intellectual property management and the role of economic modelling in driving research and development direction and paving the way for commercialisation.

Introduction

The Sugar Milling Research Institute (SMRI) is a research organisation funded primarily by the southern African sugarcane processing industry and the research arm of the Institute is almost wholly funded from this source. In 2005, the SMRI identified the need to revise its research strategy, in light of a highly competitive marketplace, both domestically and internationally, and the pressure placed on the South African sugarcane industry from diverse factors. The South African sugarcane processing industry already operates at high levels of efficiency and relatively low costs of production by international standards, leaving little scope for using existing technologies to make substantial improvements in efficiencies and costs.

This led the SMRI to embark upon an ambitious new research strategy in 2006 to develop technologies and new products capable of creating step-change opportunities, fully aligned with the strategic objectives and needs of the industry (Dewar and Davis, 2007). In doing this, the SMRI moved away from incremental to much more innovative, high-impact research with potentially greater commercial rewards for its members.

SMRI researchers were encouraged to think laterally and to investigate other industries for technologies that could be used in sugarcane processing, and which could result in significant cost savings or recovery increases.

Cane preparation had been identified as a high cost area of the process, because of the labour and maintenance costs associated with wear of knives and shredder hammers. The first major project to be identified within this new research strategy was to find a way to replace conventional cane preparation equipment with a process that has minimal wearing parts, which it was postulated would reduce maintenance costs and reduce the regular shunts for maintenance.
The nature of this project brought with it a number of challenges which needed to be worked through including, but not limited to, intellectual property (IP) management, economic modelling, and scenario identification and modelling around the potential market for the technology. The development of the process and the learnings that have come with it are discussed in this paper.

The Prepex idea

The Prepex process was born from a demonstration of high-pressure water jetting, and the idea that it might be used to shred sugarcane. A quick test with suitable portable equipment showed that high-pressure water could indeed shred cane very finely. It was clear that this innovative approach could eliminate the maintenance and labour costs associated with regular replacement and hard-facing of the wearing parts in conventional cane preparation equipment, and could reduce the frequency of factory stops required for this replacement. It was envisaged that as a consequence of its ability to shred the cane finely, the water jetting process could not only replace conventional preparation equipment, but it could perhaps combine preparation and extraction into one unit operation (Figure 1), with obvious cost savings. Hence the name ‘Prepex’ (Preparation/Extraction) was coined.

![Fig. 1—Outline of Prepex process.](image)

From an early stage it was realised that two of the key factors that would determine the commercial feasibility of Prepex were the amount of water required to shred the cane, and the energy required to do so. The first factor not only influences the energy required directly, but any more water used for the preparation and extraction in excess of current imbibition added would bring an additional energy penalty for evaporation. Hence, it was necessary to develop a test rig to determine the water and energy requirements.

Need for confidentiality

It was obvious that, should the Prepex technology prove successful, it would need to be exploited appropriately, and that the SMRI members should get the benefit of having funded the development. Thus, protection of the idea and know-how at an early stage was critical to ensure that a formal IP protection route could be followed if deemed appropriate. Confidentiality around the new idea had to be assured. This entailed consideration of:

- **In-house confidentiality.** Scientific researchers are taught to publish their results in journals and at conferences and are keen to share their experiences with other experts in the same field. When working on new, possibly ground-breaking, technologies, this is not always the desired behaviour. It may be necessary to keep the invention, design, project, and the scientific work confidential until the IP has been properly protected. For Prepex, this required a change of behaviour on the part of the researchers, and also required that measures above and beyond the standard Confidentiality Agreements required by the company were put in place. This included frequent reinforcement of the need for confidentiality with employees, not solely the researchers, but every member of staff who assisted with research, documentation, analysis, and any other work to do with the project.
• **Collaborator/Partner/Supplier/Service provider confidentiality.** During the Prepex project, the SMRI team required particular information (for example, the specifications and costs of very high pressure pumps with particular materials). Before revealing any of the process know-how or even the Prepex concept to potential collaborators, suppliers, or service providers, it was necessary to ensure that there was a comprehensive Non-Disclosure Agreement (NDA) in place to protect the potential IP. This led to delays in the research as these NDAs were negotiated and signed. The terms of the NDAs included the requirement that the other party also had agreements in place with their employees to ensure that the NDA was adhered to across the company.

• **Distribution of reports.** The SMRI’s Advisory Research Committee (ARC), which comprises industry, scientific and academic representatives, meets twice yearly to guide research direction and to oversee progress of current research areas and to ensure that the SMRI Research Program remains relevant to the industry’s needs. In order to keep SMRI member factories, and more specifically the ARC, informed of progress and to retain their support to continue work on Prepex, it was necessary to provide regular progress reports. There was thus a play-off between maintaining confidentiality and providing information each time a report was issued. To reduce the risk of premature leakage of IP, the SMRI was forced to produce reports that contained indications of success, as well as any problems that needed to be overcome, without revealing the intricate details of the IP. It was also necessary to differentiate what information was distributed to the ARC, and what was disclosed to the general membership via monthly reports. Raising awareness with the ARC of the need for confidentiality of the information shared with them was also a new requirement of the SMRI’s new research strategy.

**Techno-economic modelling**

It is well-appreciated at the SMRI that, in order for research to be considered successful, it must be directed towards achieving outcomes, namely the commercial implementation of technologies, processes and products derived from the research. Hence, evaluation of the merits of a research project must be done on the basis of both technical and commercial risks and potential rewards, to both the SMRI and its members.

Consequently, it is necessary at an early stage in the project to develop a techno-economic model that can provide insight into these areas. The detail and accuracy of the information contained in the economic model will likely increase as the project progresses.

Where a technology will replace an existing process, as with Prepex, this allows one to know what the boundaries are relating to costs. For Prepex, rough estimates of costs were used initially, but as the project progressed, the numbers in the model were refined as information was gathered.

Regular updates of the model allowed the research team and the ARC to make informed decisions on the viability of Prepex, as well as decisions on how the perceived costs, or risks, weighed against the perceived rewards should the technology be implemented. An important aspect of such a model is that it should include sensitivity analyses to direct research towards the key elements that have the greatest influence on the economic feasibility of the technology.

The model used for the Prepex technology compared the existing technology costs with those of the Prepex process, and included costs such as:

- Annualised capital costs. These were based on major items, such as knives, shredders, diffusers and mills, with percentages applied for ancillary items.
- Annual maintenance costs;
- Annual labour costs, where savings could be made;
- Energy costs.
Although the first three costs sound simple to determine, it was difficult to get accurate values for existing preparation and extraction installations. Of the three, capital costs should be the most accurate, as data from projects involving new factories, or capacity increases, are fairly readily available. Companies are, however, often reticent to divulge these numbers. Accurate maintenance and labour costs for particular areas of the factory were even more difficult to come by for a number of reasons. This area is one where sugar companies can compete on production costs and, as such, they are often unwilling to divulge information that may assist a competitor. Secondly, factories do not always maintain accurate records of maintenance and/or labour costs for each section of the factory. It was therefore necessary to estimate these costs for the project economic reviews.

At the early stage of development of Prepex there was poor technical definition of the size and nature of the equipment required. As the project progressed, it was possible to refine these costs only slightly as the plant design could not be finalised. Maintenance costs depend on the reliability of equipment and maintenance cycles required. In the case of new technologies, these may need to be estimated for the entire project life cycle, until a demonstration plant is in operation. In the case of Prepex, suppliers of the major equipment could not provide any reliable data on the maintenance or replacement frequency of the equipment, such as nozzles and high pressure pumps and, consequently, estimates had to be used. Conservative ‘worst-case’ estimates are often used, which could affect the viability of the new technology detrimentally, but for Prepex the research team and its industry-appointed advisors used their engineering judgement to estimate realistic values.

Technical development

Laboratory experimental work

A small rig (Figure 2) was constructed at the SMRI for testing of the principles and to gain an understanding of the key factors affecting the efficiency of the Prepex process. This rig was capable of processing only a few stalks of cane at a time and for short durations only (2–10 seconds). Nevertheless, it enabled several different types and configurations of nozzles to be tested, and allowed the project team to get an idea of what was possible and what wouldn’t work. However, although the rig enabled the team to shred cane completely and rapidly (Figure 3), it was clear that it would be difficult to optimise the energy and water consumption because of edge and start-stop effects associated with the small rig. At this stage, it was realised that a larger rig would be required, which would be able to generate sufficient shredded cane for initial extraction trials to progress, and a request for such a rig was taken to the ARC for support.
However, because of the radical nature of the technology and the conservativeness of the world sugar industry, the ARC guided the SMRI research to focus initially on preparation only, rather than develop the combined Preparation/Extraction technology. This was not entirely in line with the project team’s thinking, as the maximum benefit was believed to come from the combination of preparation and a simplified extraction process. Nevertheless, the ARC approved the budget to construct a larger rig that was capable of handling up to 60 kg of cane at a time.

![Cane shredded with Prepex.](image)

This larger rig was built (Figure 4) and testing commenced. One of the factors that was believed to limit the efficiency achieved with the first rig was the pressure of the water. The new rig was designed to handle a higher pressure, but the cost of a pump to supply the pressure and flow-rate was prohibitive, so a suitable pump for testing was borrowed from a commercial high pressure cleaning company. However, the limited availability of the pump meant that an extensive experimental program could not be carried out, and unavoidably delayed the rate of progress.

![Larger Prepex rig.](image)

The trials that were performed showed that the technology certainly had great potential, and that energy requirements were in line with those of current preparation equipment. Some concern was again expressed about the amount of water required, and how this would impact on the extraction achieved in the following step. It was postulated that a way around this would be to use juice instead of water for the shredding. The major problem that was encountered was sourcing
pumps that could pump sugar juice at the flow rates and pressures required. Most pump manufacturers contacted were unwilling to commit to quoting for a unit for this duty, and one pump that was considered suitable was extremely and unrealistically costly because of the uncertainty about the effects of the high pressure juice on the pump internals. This information was fed back into the economic model, and somewhat changed the outlook for the viability of the technology.

**Upscaling the technology for commercialisation**

In order to get more certainty about the energy and water consumption, and to better define the technical details with a view towards commercialisation, the next stage was to design and build a pilot plant at a factory. The SMRI realised that for the technology to become a success and to be transferred to the marketplace where commercial outcomes could be realised, it was appropriate to engage with a company that would be able to assist the SMRI to scale-up the technology through to commercialisation. It became clear that a simple ‘arm’s length’ transaction with a party was not going to be appropriate, and a partnership would be required. A potential partner would want to be assured of the technical and commercial potential of the technology and share in the subsequent commercial returns from the technology.

The appropriate time to bring a partner on board requires some thought, considering the balance between the increased likelihood of commercial success and the share of the eventual returns. Detailed agreements on IP sharing are required, i.e. what background IP each of the parties possess and how foreground IP developed during the partnership will be shared.

The process to decide on an appropriate partner for Prepex required considerable debate, in that some of the obvious candidates were already involved as SMRI members or were direct competitors in technology development. Thus it became necessary to develop and agree on a set of evaluation criteria that could be used objectively to rate each candidate’s suitability, and an expression of interest was called for from the short-listed candidates. In the end, a suitable partner was selected but, by this stage, the time was rapidly approaching for the national patenting applications, and there were still some technical and commercial hurdles to be addressed.

A brainstorming session was held with the chosen partner to agree on the way forward and the appropriate way of developing the technology. The technical success of the technology was recognised, but some peripheral technical hurdles could only be addressed by further expenditure on a pilot plant. However, the cost of pumps to pump juice appeared to be a major factor in the economics, and there was insufficient information available to reduce the uncertainty and risk associated with these costs. It was agreed that, given the current information available to the parties, the commercial risk did not warrant investment in a pilot plant and further work at this stage.

**IP protection**

**Early considerations**

In parallel with the technical development, formal protection of the IP was considered. The first decision to be taken was whether to patent at all. Just because an idea is patentable does not necessarily mean that it should be patented. Issues that need to be considered are the costs of patenting, the chances of being able to exploit the patent, the willingness of the organisation and its stakeholders to protect, enforce and defend the patent, and how the patent would be linked with the technology exploitation plan.

Once it has been decided to patent, the decision as to when to patent must then be made. It is generally advisable to delay the formal IP protection process until sufficient information has been obtained to decide on the likelihood of technical and commercial success, but the decision as to when to patent is not always easy. There is a need to balance the risk of the idea being leaked and thus entering the public domain, which will jeopardise the granting of protection by the relevant authorities, with the risk of someone else developing the idea in parallel and lodging proprietary protection in advance.

Although most countries abide by the ‘first to protect’ principle, some countries, notably the USA, abide by the ‘first to invent’ principle. In such cases it may be possible to challenge IP
protection based on dated records kept of meetings, brainstorming sessions, research work, or any other associated ideas. Similarly, such detailed records are important with regards to NDAs signed with collaborators, service providers and the like in terms of establishing background IP. Although it is accepted practice for scientists to document work in a laboratory workbook, it is less common for engineers to do this as engineers tend to be more interested in solving the problems than in recording how. Keeping of detailed dated records of modifications made and new ideas that were tried was a necessary behavioural change that the Prepex research engineers had to embrace.

**Provisional patent protection**

With regards to the Prepex technology, the SMRI lodged a South African provisional patent in February 2006. This started the clock ticking for development of the technology to the point where a strong and well-defined full patent application could be submitted. However, delays in sourcing and installing some of the equipment meant that time was running out on the provisional patent, and insufficient results were available to be sure of the viability of the technology. One option was to allow the first provisional patent to lapse and to apply for a new one. This carried the risk that anyone who had developed the same technology in parallel and had applied for a provisional patent before the second Prepex provisional patent was taken out would get priority. However, the risk associated with this was considered very small, and the decision was made to buy the extra time with this option, with the follow-up provisional patent being lodged in February 2007.

As work on the project proceeded, the ARC agreed that there was sufficient commercial potential in the technology to apply for a Patent Co-operation Treaty (PCT) provisional patent. Writing this application required considerable debate about what should be included. Considerations included:

- Should the patent cover the process (i.e. the use of high pressure liquid to shred cane) or the product (the details of the equipment to achieve this)?
- Should the patent cover preparation only, or be extended to cover extraction as well?
- Should the patent cover applications beyond preparation of sugarcane to produce sugar to include ethanol as well?
- What are the key elements of the technology that are patentable and protectable?
- What competing technologies were in the public domain, including other patents?

In the end, these questions were resolved, but it was clear that the level of knowledge required to answer them went beyond the experience of the technical project team who had started the project. Other team members with more experience in IP and commercialisation were brought in to assist with these issues. Finally, a PCT patent application was submitted in February 2008 (Loubser and Gooch, 2008). Feedback from the International Preliminary Examination Authority was that all claims were found to be both novel and inventive.

**National phase patenting**

When considering the appropriate strategy for national phase patenting, several issues come into the picture. It is necessary to identify in what countries the protection is to be sought, as each country requires a separate application, with resultant costs. These costs include legal fees for compiling the patent filings, translation costs where required in non-English speaking countries, the actual filing costs and annual fees for maintaining the patents. Potential costs for enforcing patents also need to be considered.

Identification of the countries in which to patent requires knowledge of the potential markets in order to determine whether the potential returns would cover the protection costs. These could include countries where the technology may be installed, manufactured for use in other countries or further developed. In the case of sugar factory applications, the market size is probably the easiest to ascertain. The number of factories world-wide, and by country, is readily available. More difficult is an estimation of market penetration. Points that need to be considered include:
• Would the technology only be installed in new installations?
• Would the technology be installed to replace worn-out or obsolete equipment?
• Would the technology be installed to replace functional existing equipment?
• Would the technology be installed for capacity increases?

Factors which affect the above decisions are mainly the capital and operating costs and the return on this investment. If the returns are significantly higher than for existing technologies, then there is a case for replacing equipment and reaping the rewards as soon as possible. If the benefits are lower, then the technology may only be used for some of the other scenarios.

Another factor for consideration in the scenario analysis is the industry itself. What barriers to entry exist in the industry with regards to new technologies? The sugar industry has shown itself to be fairly conservative, with the uptake of new technologies (e.g. wholestick shredders and diffusers) to be fairly slow, despite the apparent advantages. This consideration could have a significant effect on the market penetration of a new technology, and should be borne in mind for IP management. Patents have a finite lifespan, and the likely number of installations completed in this time is of significance.

While taking account of the assessed commercial risk when national phase patenting decisions had to be made, the SMRI Board was appreciative of the potential impact of the technology which may be realised should some of the existing constraints change or an opportunity arise to exploit the Prepex technology (for example, together with a simplified extraction technology). The Board therefore approved that the technology be patented in South Africa, being the home country, and in Brazil, being the country of greatest growth and expansions and where suitable applications were most likely to arise.

**Conclusions and key learnings**

The Prepex project has been the first major project for the SMRI since the implementation of its ambitious new research strategy. As such, the learning curve has been extremely steep. Irrespective of the outcome of this particular project, the information gathered will stand the Institute in good stead going forward in its quest for radical new technologies that will revolutionise the sugar industry. The key lessons learnt are summarised:

• R&D needs to be aligned with industry strategic objectives – i.e. it must be relevant.
• Assess the techno-economic potential of various projects as early as possible and invest in those where there is a higher chance of successful outcomes.
• There is more to a commercial outcome/success than a good idea and a technically proven technology. Commercial issues may be more difficult than the technical ones.
• It is important to develop an economic model early and update it frequently.
  o Include sensitivity analyses.
  o Identify key hurdles and direct R&D efforts to resolve them.
• Understand the importance of collaboration – different skills feature strongly at different phases of the innovation process.
• Realise the importance of good IP management.
  o IP awareness among all stakeholders – researchers, support staff, members/sponsors, collaborators, suppliers – is critical.
  o Need to look at ways of keeping interest/support of members/sponsors without divulging key details (risk of IP leakage).
  o Ensure that membership rights are reserved.
  o Don’t waste time innovating in areas where you are already locked out by prior patents/public domain issues – keep abreast of the state-of-the-art.
  o NDAs must be in place before discussions with outside parties and this can slow down the development process.
o It is critical to maintain a detailed paper trail of developments and discussions.

• Patenting decisions are complex.
  o Whether to patent – just because the technology is patentable does not mean that one should patent the technology.
  o When to patent – there is a trade-off between needing sufficient knowledge about the technology to lodge a strong patent and the risk of IP leakage or being piped at the post by a competitor.
  o Where to protect – this is driven by the exploitation strategy, cost: benefit assessment, potential take-up of the technology, conservativeness of the industry, and so on.

• Learn from your mistakes and successes, and use the lessons the next time.
• If failure seems likely, fail quickly – otherwise it can be VERY expensive.
• Decision-making is required at each stage to upscale the technology.
  o The more certainty required, the more it tends to cost.
  o When the certainty is not there, the decisions tend to come down to the potential of the technology (Prepex: potential = MASSIVE) versus the technical/commercial risks and the investment required.

• Above all, if you do not try, you will never succeed!

REFERENCES


NOUVELLE STRATEGIE RADICALE DE RECHERCHE AU SMRI: QUELQUES RESULTATS DU PROJET PREPEX

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Mots clés: Prepex, Recherche, Commercialisation, Brevet.

Résumé

EN 2006, le Sugar Milling Research Institute (SMRI) a entrepris une nouvelle stratégie de recherche ambitieuse pour développer des technologies capables de créer des opportunités de changement radical pour la transformation dans l’industrie de la canne à sucre sud-africaine. Ce faisant, le SMRI a réduit les projets de moindre importance pour des recherches novatrices, avec un potentiel de gains commerciaux plus importants pour ses membres. Le premier projet majeur à être identifié dans le cadre de cette nouvelle stratégie a été le projet ‘Prepex’, qui vise à remplacer le matériel de préparation de canne à sucre traditionnelle avec des composants qui résistent à l'usure afin de minimiser les arrêts pour le remplacement des couteaux et des marteaux. Des essais à petite échelle et en laboratoire furent entrepris, et un modèle économique détaillé a été développé afin d'évaluer la viabilité technique et commerciale du projet. La technologie a été prouvée et un brevet a été déposé. Les résultats présentés dans ce document incluent la gestion de la propriété intellectuelle et le rôle de la modélisation économique de la recherche et du développement ouvrant la voie à la commercialisation.

NUEVA ESTRATEGIA RADICAL DE INVESTIGACIÓN EN EL SMRI: ALGUNOS APRENDIZAJES DEL PROYECTO PREPEX

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PALABRAS CLAVE: Prepex, Investigacion, Comercialización, Patente.

Resumen

EN 2006, el Instituto de Investigación de Molienda de Caña (SMRI) se embarcó en una nueva y ambiciosa estrategia de investigación para desarrollar tecnologías capaces de crear oportunidades de ‘cambio de nivel’ para la industria procesadora de caña de Sudáfrica. Al hacer esto, el SMRI pasó de realizar mejoras incrementales a una investigación más innovadora con mayores beneficios potenciales para sus miembros. El primer gran proyecto de esta nueva estrategia fue el proyecto ‘Prepex’, que busca el reemplazo de los equipos convencionales utilizados para la preparación de caña por equipos con componentes que no se gastan, con el propósito de minimizar el tiempo de reemplazo de éstos. Se realizó investigación a pequeña escala en laboratorio y planta piloto, se desarrolló un modelo económico detallado y se realizó un estudio de mercado para determinar la viabilidad técnica y comercial del proceso. La tecnología fue comprobada y patentada. Los conocimientos descritos en este trabajo incluyen el manejo de la propiedad intelectual y el rol del modelamiento económico para conducir la investigación y el desarrollo y construir el camino hacia la comercialización.
THE PREPARATION OF HUMAN RESOURCES FOR SUGARCANE IN MEXICO

By

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KEYWORDS: Sugarcane, Human Resources.

Abstract

The University of Veracruz (U.V.) is a public institution that has historically been recognised, both nationally and internationally, for its work in the fields of art and literature. However, U.V. is located in the Mexican State with the highest sugar production of the country and, therefore, in recent times has focused on social, cultural and technological aspects of the local community within which U.V. finds itself, particularly in this significant agro-industry of Mexico. The Institute for the Improvement of Sugar Production (IMPA), founded in 1949, was the institution that sponsored research in this area, but this entity closed in 1990. This was the main catalyst that led the University of Veracruz, jointly with other centres, to initiate a program to prepare students for a career in the sugarcane sector in Mexico. A total of 57 sugar mills operate in Mexico, which are distributed throughout 15 states and produce over 5.5 million tonnes of sugar. The State of Veracruz contributes 41% of the national production. Eleven of its factories are located in the region of Cordoba, where the MSc program ‘Sugar Cane Cultivation and its Impact on the Environment and Social-Economic Factors’ has been implemented. Based on the previous 40 MSc students of ‘Management and Use of Sugar Cane Agricultural Systems’, 8 students have qualified and the remaining are expected to qualify at the end of 2010. Currently, nine graduates are working in sugar mills within the Cordoba region. The paper shows all the characteristics of the MSc program and its relationships to the agro-industry of Mexico, through the research project and technological improvement, and offers several results of the finalised research. The preparation of highly trained human resources for the sugar cane industry is the essential goal of this program.

Introduction

In México, 57 sugar mills, distributed throughout 15 states of the Republic, are operating and grow over 650 thousand hectares of sugarcane, within 4 agro-climatic regions along west and east coasts of the Pacific Ocean and the Gulf of Mexico-Caribbean Sea at 19º latitude, (Marín, 1998; Flores, 2001). Production amounts to more than 49 million tonnes of cane and five million tonnes of sugar, with cane yields ranging in recent years between 64 and 72 tonnes/ha and factory recovery (commercial cane sugar) around 11% (Manual Azucarero Mexicano, 2008). That the industry supports, directly or indirectly, more than three million Mexicans. Veracruz comprises approximately 41% of the national production with 22 sugar mills, of which 11 are in the Cordoba Region, where the University of Veracruz (U.V.) is situated.

This University is a public institution with significant national and international stature. Being in the heart of the Mexican sugar industry, the U.V. has been associated with the sugar industry in social, cultural and technological fields. Consequently, when the former Institute for the Improvement of Sugar Production (IMPA) closed in 1990, the U.V., in collaboration with the
National Program of Research in Sugarcane Science and Technology and with the Latin America and Caribbean sugar exporting countries group, initiated a specialised sugarcane related program in 1993, which came to fruition in June 1995. This experience fostered a strategic alliance between the organisations and enabled the establishment of the Masters degree of ‘Management and Use of Sugarcane Agro systems’ in December of 1996.

The objective of this course was to provide the local sugar industry with highly qualified personnel, with 56% of the teaching staff having a Ph.D. degree. This high level teaching experience comprises staff having qualified at the University of Veracruz (U.V.) including its Library and Information Services Unit (USBI), the Autonomous University of Chapingo (ACH), the National Chamber of Sugar and Alcohol Industries (CNIAA), DGETA, the Veracruz, Oaxaca and Puebla sugar mills, and the Orizaba High Tech Lab (LATO-U.V.), all from Mexico, and internationally: the National Sugarcane Research Institute (INICA) of the Ministry of Sugar (MINAZ) of Cuba, the Havana Agricultural University (UNAH), CENGICAN, the University of San Carlos and Pantaleon Sugar Mill of Guatemala, the Luis de Queiros Higher Agriculture School of the University of Sao Paulo (ESALQ) of Brazil, and the Sugarcane Research and Extension Division (DIECA) of Costa Rica.

Program goals

The program goals are to prepare human resources, which may contribute to the development of a competitive, diversified and sustainable sugarcane agro-industry, able to design, lead and conduct programs of applied research, training and technological innovation in sugarcane, linked to the agro-industry and to the environment.

General characteristics of the program

The general characteristics of the program are as follows:

- Two years of postgraduate study (four semesters), including a dissertation or thesis work, except certain cases in which the research project requires a longer period, which must be certified by the tutor of the thesis and which cannot be more than one year.
- The student must submit a thesis title, at the beginning of the study program, which, once approved by the tutor, can be submitted to the Masters coordinator from which time the student has a two year period to finish his (her) thesis or to timely apply for an extension.
- The Study Plan is composed of 19 subjects, comprising three main groups; viz Methodological Training, General Agricultural Training and Specific Sugarcane Training. 14 of the subjects are compulsory and one elective subject needs to be selected from the remaining five. Furthermore, the program includes two activities as program requirements: the writing of a dissertation or thesis and an exam. This comprises a total of 1125 hours, of which 585 hours are of theoretical preparation and 540 of practical training. Tables 1 and 2 highlight the work hours and academic credits associated with the course as well as the broad curriculum structure.
- Students must also obtain Level II English and/or French Language as well as demonstrate computer use proficiency that may be acquired from institutions accredited by the Ministry of Public Education before the degree is awarded.

Applied research lines of the program

The dissertation or thesis projects of the students generally focus on the current research needs within the local sugar industry at that time but are confined to the broad areas of:

- Sugarcane breeding and selection.
- Sugarcane agricultural technology.
- Sugarcane byproducts, biotechnology and the environment.
- Sugarcane plant protection.
Table 1—Curricular structure by training areas.

<table>
<thead>
<tr>
<th>Area of Training</th>
<th>Total No. of Hours</th>
<th>%</th>
<th>Total No. of Credits</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methodological</td>
<td>255</td>
<td>22.67</td>
<td>26</td>
<td>22.81</td>
</tr>
<tr>
<td>General Agricultural</td>
<td>300</td>
<td>26.67</td>
<td>30</td>
<td>26.31</td>
</tr>
<tr>
<td>Sugarcane Specific</td>
<td>570</td>
<td>50.66</td>
<td>58</td>
<td>50.88</td>
</tr>
<tr>
<td>Sub Total</td>
<td>1125</td>
<td>100.00</td>
<td>114</td>
<td>100.00</td>
</tr>
<tr>
<td>Dissertation work</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Degree Exam</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>139</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*585 Hours Theoretical (78 credits) and 540 Hours Practical (36 credits).

Table 2—Curricular structure by subjects.

<table>
<thead>
<tr>
<th>Methodological</th>
<th>Agricultural general</th>
<th>Sugarcane specific</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1. Methodology of research</td>
<td>1. Edaphology</td>
</tr>
<tr>
<td></td>
<td>2. Statistical methods and experimental design</td>
<td>2. Soil fertility*</td>
</tr>
<tr>
<td></td>
<td>3. Company management</td>
<td>3. Agro ecology</td>
</tr>
<tr>
<td></td>
<td>4. Agricultural economics*</td>
<td>4. Water resources and drainage*</td>
</tr>
<tr>
<td>5. Workshop I of dissertation</td>
<td>5. Seminar I</td>
<td>4. Agricultural mechanisation *</td>
</tr>
<tr>
<td></td>
<td>7. Sugarcane byproducts*</td>
<td>7. Sugarcane byproducts*</td>
</tr>
<tr>
<td></td>
<td>8. Seminar II</td>
<td></td>
</tr>
</tbody>
</table>

Note: 19 Subjects: 14 compulsory or obligatory, 5 Optional* (to select 1).

Requirements of the program include writing of the dissertation or thesis and the degree examination.

Academic results

Admissions and exits

During the period 1997 to 2008, ninety-seven (97) students registered, of whom 40 have graduated, amounting to 41% of the total number of registered students (Table 3). The masters graduated are, in large majority, working in various sugar mill plantations and other agro-industrial enterprises of the country, with excellent production and social achievements.

Table 3—Graduated students up to December 2008.

<table>
<thead>
<tr>
<th>Generation</th>
<th>Dates Beginning</th>
<th>Dates End</th>
<th>Registered</th>
<th>Graduated</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Jan/1997</td>
<td>Dec/1998</td>
<td>21</td>
<td>18</td>
<td>85.71</td>
</tr>
<tr>
<td>2</td>
<td>Jan/2001</td>
<td>Dec/2002</td>
<td>19</td>
<td>6</td>
<td>31.58</td>
</tr>
<tr>
<td>3</td>
<td>Aug/2002</td>
<td>Jul/2004</td>
<td>26</td>
<td>10</td>
<td>38.46</td>
</tr>
<tr>
<td>4</td>
<td>Aug/2004</td>
<td>Jul/2006</td>
<td>20</td>
<td>4</td>
<td>20.00</td>
</tr>
<tr>
<td>5</td>
<td>Aug/2006</td>
<td>Jul/2008</td>
<td>11</td>
<td>2</td>
<td>18.18</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td>97</td>
<td>40</td>
<td>41.24</td>
</tr>
</tbody>
</table>

Training for growers and field technicians of the sugar mills

Since 2002, the Masters Degree program has also been conducting training courses for growers and field technicians in the following subjects: Sugarcane Pest, Disease and Weed Management, Varieties and Seed cane, Nutrition and Fertilisation, Field Management, Sugarcane Quality, Sugarcane By-products and Crop Harvesting. Until December 2008, twenty courses have been made available, with 614 students from 57 sugar mills attending, and 22 postgraduate professors have delivered classes. Relationships with other national and international institutions and enterprises

Practical tours arranged by the professors for the students have been arranged with the support and collaboration of the following institutions and countries:

• To the National Sugarcane Research Institute (INICA) Cuba, during years 2002,
• To CENGICAÑA, Pantaleon Sugar Mill and the University of San Carlos, Guatemala, in years 2001, 2002, 2004 and 2006.
• To ESALQ and CENA of the University of Sao Paulo, Brazil, in years 2005, 2008 and to CINCAE of Ecuador in 2005.
• To DIECA, Costa Rica, in year 2007.

Furthermore, support has been received to fulfil student's project tasks by the following sugar mills: Central Motzorongo, San Miguelito, Central Progreso, San José de Abajo, El Potrero, La Providencia, Constancia, La Margarita, Tres Valles, Adolfo López Mateo, El Modelo, Calipam and Huixtla.

Main research results attained

• Characterisation of the main commercial, promising and traditional sugarcane varieties of Mexico. Through various student dissertation (thesis) projects and the available information, the botanical and agro-industrial characterisation of the most important sugarcane varieties of the country, including photos and ripening curves, was carried out, including the following varieties: Mex. 69-290, CP 72-2086, Mex 79-431, Mex 57-473, Co 997, Q 96, SP 70-1284, RD 75-11, My 5514, ITV 92-1424, PR 66-2231, CMex 93-45, CMex 93-49, MotzMex 91-207, AteMex 96-40, C86-12, NCo 310, L 60-14, POJ 2878, B 4362 and Co. 421 (Hernández, 2004; Patiño, 2005).

• Characterisation and control of the main weeds of sugarcane in the region ‘Central Veracruz’, Mexico. Through various student dissertation (thesis) projects and the available information, the descriptive characterisation, distribution, propagation and integrated control of the 50 most important weeds, by their level of hazard to sugarcane, which include the following number of weeds by families: Poaceae, 17; Cyperaceae, 2; Amaranthaceae, 4; Compositae, 8; Commelinácea, 1; Portulacaceae, 2; Solanácea, 1; Papaveraceae, 1; Malvaceae, 2; Leguminosae, 3; Convolvulácea, 1; Acanthaceae, 1; Cucurbitaceae, 1; Euphorbiaceae, 3; Fabaceae, 1; Araceae, 1 and Boraginaceae, 1. (Ordóñez, 2002; Vilaboa, 2003; Illescas, 2004; García, 2008).

• Nitrogen fertilisation of sugarcane in San José de Abajo and San Miguelito Sugar Mills, Veracruz, showed no response in the plant cane cycle, nor to split application of this nutrient, under the prevailing rainfed conditions, in San José de Abajo Sugar Mill, both in cane yield or in sugar recovery. In the second ratoon cycle, under rainfed conditions, in San Miguelito Sugar Mill, nitrogen fertilisation positively influenced cane yield, and through this the pol or sucrose yield per hectare (Table 4), but not in a split application. An optimum rate of 140 kg/ha was found (Figure 1) (Escarola, 2003; Norato, 2004).

• Sugarcane potassium fertilisation on Cambisol soils, of San Miguelito Sugar Mill, Córdoba, Veracruz, México. At planting of trials, due to inadequate monoculture and crop agronomic management, losses of soil nitrogen (0.11%), organic matter (1.55%) and potassium (16.5 K₂O/100 g) had taken place, producing changes in the category of these components (Tables 5 and 6). Treatments of 150 and 225 kg of potassium per hectare and fixed levels of 167 and 0 kg/ha of nitrogen and phosphorus, respectively, resulted in significantly higher tonnes cane/ha/month, percentage of pol/cane and tonnes sugar/ha/month in plant cane while, in first ratoon, only the treatment of 225 kg potassium per hectare was higher (Tables 7 and 8). (Arreola, 2002; Niño, 2007; Colorado, 2008).

Table 4—Results of tonnes cane/ha, Pol % cane and tonnes pol/ha at harvest,
second ratoon cycle, in the locality of Tapia, San Miguelito Sugar Mill, Córdoba, Veracruz.

<table>
<thead>
<tr>
<th>No.</th>
<th>Treatments</th>
<th>Mean values and formation of groups by LSD</th>
<th>tonnes cane/ha</th>
<th>Pol % cane</th>
<th>tonnes Pol/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>00-00-00</td>
<td>87.7 – – c</td>
<td>17.47</td>
<td>15.23 – – c</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>177-85-85</td>
<td>119.1 A – –</td>
<td>18.01</td>
<td>21.34 a b c</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>00-60-120</td>
<td>93.6 – b c</td>
<td>17.98</td>
<td>16.83 – b c</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>50-60-120</td>
<td>111.1 A b –</td>
<td>17.82</td>
<td>19.88 a b c</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>100-60-120</td>
<td>114.3 A – –</td>
<td>18.02</td>
<td>20.35 a b c</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>150-60-120</td>
<td>109.6 A b –</td>
<td>18.16</td>
<td>20.46 a b c</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>200-60-120</td>
<td>113.1 A b –</td>
<td>18.24</td>
<td>21.35 a b c</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>150–60-120</td>
<td>114.3 a b –</td>
<td>18.21</td>
<td>21.28 a b c</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>150–60-120</td>
<td>121.5 a – –</td>
<td>18.64</td>
<td>22.65 a c d</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>150–60-120</td>
<td>116.5 a – –</td>
<td>18.57</td>
<td>21.68 a b c</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LSD 0.05</td>
<td>20.60</td>
<td>3.03</td>
<td>5.39</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1—Results of cane yield under various nitrogen dosages in a 12 months old, second ratoon cycle, at San Miguelito Sugar Mill (Inflexion point: 140 kg N/ha, expected yield 115 tonnes cane/ha).

Table 5—Category reached by the various cropping techniques for variables total nitrogen, organic matter and pH.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total nitrogen</td>
<td>Organic matter</td>
<td>pH</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>Class</td>
<td>Class</td>
<td>Class</td>
</tr>
<tr>
<td>Soil without sugarcane</td>
<td>0.28</td>
<td>Extremely rich</td>
<td>3.35</td>
</tr>
<tr>
<td>during 15 previous years</td>
<td></td>
<td></td>
<td>5.50</td>
</tr>
<tr>
<td>Soil with sugarcane</td>
<td>0.16</td>
<td>Rich</td>
<td>2.17</td>
</tr>
<tr>
<td>without harvest burning</td>
<td></td>
<td></td>
<td>5.70</td>
</tr>
<tr>
<td>Soil with sugarcane</td>
<td>0.17</td>
<td>Rich</td>
<td>1.80</td>
</tr>
<tr>
<td>with harvest burning</td>
<td></td>
<td></td>
<td>5.10</td>
</tr>
</tbody>
</table>

Table 6—Category reached by the various cropping techniques for variables...
phosphorus, potassium and cation exchange capacity.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P₂O₅/100g</td>
<td>K₂O/100g</td>
</tr>
<tr>
<td>Soil without sugarcane during 15 previous years</td>
<td>5.20</td>
<td>High</td>
</tr>
<tr>
<td>Soil with sugarcane without harvest burning</td>
<td>5.60</td>
<td>High</td>
</tr>
<tr>
<td>Soil with sugarcane with harvest burning</td>
<td>6.20</td>
<td>High</td>
</tr>
</tbody>
</table>

**Table 7**—Results of harvest variables in a 17 months old, plant cane cycle, at San Miguelito Sugar Mill, Córdoba, Veracruz.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>tonnes cane/ha/month</th>
<th>Pol % cane</th>
<th>tonnes Pol % cane/ha/month</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (00-00-00)</td>
<td>8.38 – b</td>
<td>12.07 – b</td>
<td>1.01 – b</td>
</tr>
<tr>
<td>2 (167-75-75)</td>
<td>9.35 A b</td>
<td>12.77 a b</td>
<td>1.19 a b</td>
</tr>
<tr>
<td>3 (167-00-75)</td>
<td>8.76 A b</td>
<td>13.01 a –</td>
<td>1.14 a b</td>
</tr>
<tr>
<td>4 (00-00-75)</td>
<td>8.58 A b</td>
<td>12.89 a b</td>
<td>1.11 a b</td>
</tr>
<tr>
<td>5 (167-00-00)</td>
<td>8.47 A b</td>
<td>12.62 a b</td>
<td>1.07 a b</td>
</tr>
<tr>
<td>6 (167-00-150)</td>
<td>9.64 A –</td>
<td>13.35 a –</td>
<td>1.29 a –</td>
</tr>
<tr>
<td>7 (167-00-225)</td>
<td>9.52 A –</td>
<td>13.06 a –</td>
<td>1.24 a –</td>
</tr>
</tbody>
</table>

Tukey 0.05 1.13 0.91 0.22

**Table 8**—Results of harvest variables in a 14 months old first ratoon cycle, at San Miguelito Sugar Mill, Córdoba, Veracruz.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>tonnes cane/ha/month</th>
<th>Pol % cane</th>
<th>tonnes Pol % cane/ha/month</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (00-00-00)</td>
<td>7.05 – b</td>
<td>17.47</td>
<td>1.23 – b</td>
</tr>
<tr>
<td>2 (167-75-75)</td>
<td>8.44 A b</td>
<td>18.00</td>
<td>1.52 a b</td>
</tr>
<tr>
<td>3 (167-00-75)</td>
<td>7.86 A b</td>
<td>17.90</td>
<td>1.41 a b</td>
</tr>
<tr>
<td>4 (00-00-75)</td>
<td>7.19 – b</td>
<td>17.82</td>
<td>1.28 – b</td>
</tr>
<tr>
<td>5 (167-00-00)</td>
<td>7.76 A b</td>
<td>18.03</td>
<td>1.40 a b</td>
</tr>
<tr>
<td>6 (167-00-150)</td>
<td>8.00 A b</td>
<td>18.34</td>
<td>1.47 a b</td>
</tr>
<tr>
<td>7 (167-00-225)</td>
<td>8.75 A –</td>
<td>18.51</td>
<td>1.62 a –</td>
</tr>
</tbody>
</table>

LSD 0.05 1.49 – 0.33

• Influence of sugarcane harvest residue management on cane yield at El Potrero Sugar Mill, Veracruz. When evaluating the following harvest managements: 1) Cane pre-harvest and post-harvest residue burnings (PHRB), 2) Cane pre-harvest burning, without post-harvest residue burning (WPHRB), 3) Green cane harvesting, without pre-harvest and without post-harvest residue burning (GCWPHRB) and 4) Green cane harvesting, without pre-harvest but with post-harvest residue burning (GCPHRB), it was concluded that the best treatment was No. 3: Green cane harvesting, without pre-harvest and without post-harvest residue burning, which produced 24.25 tons of cane more than burnt cane, while the lowest yield was in the green cane harvest and subsequent residue burning (Table 9), as reported by Molina (2004).

**Table 9**—Results of tonnes cane/ha, tonnes tops/ha and tonnes trash/ha at
harvest, in second ratoon cycle, at El Brinco Farm, El Potrero Sugar Mill, Veracruz.

<table>
<thead>
<tr>
<th>No.</th>
<th>Treatment</th>
<th>Mean values and formation of groups by Tukey</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>tonnes cane/ha</td>
</tr>
<tr>
<td>1</td>
<td>PHRB</td>
<td>90.38</td>
</tr>
<tr>
<td>2</td>
<td>WPHRB</td>
<td>90.50</td>
</tr>
<tr>
<td>3</td>
<td>GCWPHRB</td>
<td>114.75</td>
</tr>
<tr>
<td>4</td>
<td>GCPHRB</td>
<td>70.25</td>
</tr>
<tr>
<td></td>
<td>Tukey 0.05</td>
<td>20.08</td>
</tr>
</tbody>
</table>

Conclusions

Programs for training of human resources as presented in this paper can contribute to improve human capital for the sugarcane agro-industry. The programs require collective support of neighbouring countries for maximum effect. Many of the subjects included in the program are available as distance learning subjects, which assists in the admission of students in their own countries and the participation of professors from various countries of the world. Education and research is an important element for ensuring the sustainability of sugar industries around the world. This particular program has made an important impact in the Mexican sugar industry.

REFERENCES


LA FORMATION DES RESSOURCES HUMAINES DANS L'INDUSTRIE DE LA CANNE A SUCRE AU MEXIQUE

Par

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MOTS-CLES: Canne à Sucre,
Ressources Humaines.

Résumé

L'UNIVERSITE de Veracruz (U.V.) est une institution publique qui a été historiquement reconnue, tant au niveau national qu'international, pour son travail dans les domaines de l'art et de la littérature. Toutefois, cette université se trouve dans l'état mexicain où la production de sucre est la plus élevée du pays et, par conséquent, elle s’est concentrée ces derniers temps sur les aspects sociaux, culturels et techniques de la communauté locale au sein de laquelle elle se trouve, en particulier dans cette importante région agro-industrielle du Mexique. L'Institut pour l'Amélioration de la Production de Sucre (IMPA), fondée en 1949, a entrepris la recherche dans ce domaine, mais cette entité a fermé ses portes en 1990. Cela a été la principale raison qui a conduit l'Université de Veracruz, conjointement avec d’autres centres, à lancer un programme afin de former les étudiants pour une carrière dans le secteur de la canne à sucre au Mexique. Un total de 57 usines sucrières fonctionnent au Mexique, réparties dans 15 Etats et produisant plus de 5.5 millions de tonnes de
sucre. L'état de Veracruz contribue à 41% de la production nationale. Onze de ses usines sont situées dans la région de Cordoba, où le programme pour l’obtention d’une maîtrise en Culture de la Canne à Sucre et son Impact sur l'Environnement et les Facteurs Sociaux-Economiques a été mis en œuvre. Parmi les précédents 40 étudiants de Maîtrise en Gestion et Utilisation des Pratiques Culturales de Canne à Sucre, 8 étudiants se sont qualifiés et les autres le seront à la fin de 2010. Actuellement, 9 diplômés travaillent dans les usines sucrières au sein de la région de Cordoba. La présentation montre toutes les caractéristiques du programme de Maîtrise et ses relations avec l'agro-industrie du Mexique, à travers le projet de recherche et l'amélioration technologique et offre plusieurs résultats de la recherche finale. La formation des ressources humaines hautement qualifiées pour l'industrie sucrière est l'objectif essentiel de ce programme.

PREPARACIÓN DE RECURSOS HUMANOS PARA LA CAÑA DE AZÚCAR EN MÉXICO

Por

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D.A. RODRÍGUEZ-LAGUNES² y A. HERRERA-SOLANO²

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PALABRAS CLAVES: Caña de Azúcar, Recursos Humanos.

Resumen

LA UNIVERSIDAD Veracruzana (U.V.) es una institución pública, de reconocido prestigio en las artes y la literatura a nivel nacional e internacional, que al estar en el Estado con mayor producción azucarera en México y con el compromiso social, cultural y de desarrollo tecnológico que la sociedad le confiere, no es ajena a la problemática de la principal agroindustria del país. El Instituto para el Mejoramiento de la Producción de Azúcar (IMPA), fue fundado en 1949 y desarrolló durante muchos años importantes investigaciones de gran valor para este cultivo, pero fue cerrada en 1990. Dada esta situación la Universidad Veracruzana, en coordinación con otras instituciones, inició el programa de formación de recursos humanos en el campo de la agricultura cañera en México. En el país operan un total de 57 ingenios azucareros, distribuidos en 15 estados y producen mas de 5.5 millones de toneladas de azúcar anualmente. El estado de Veracruz contribuye con el 41% de la producción nacional. Once de estas fábricas están localizadas en la región de Córdoba, lugar donde funciona el Programa de la Maestría sobre el cultivo de la Caña de Azúcar y su impacto ambiental y socio-económico. Hasta el presente 40 alumnos de la Maestría en Manejo y Explotación de los Agro sistemas de la Caña de Azúcar han concluido sus tesis, 8 están por obtener el grado de Maestro en Ciencias de inmediato y el resto se espera que concluyan sus tesis el próximo año. En este momento están cursando el programa 9 alumnos, y todos ellos trabajan en ingenios azucareros de la región. En el presente trabajo se muestran las características generales del programa de la Maestría y su relación con la agro-industria azucarera mexicana, a través de proyectos de investigaciones aplicadas e introducción de tecnologías y se ofrecen varios resultados de las investigaciones finalizadas. La preparación de los recursos humanos para la agro-industria azucarera es el principal objetivo del presente programa.
TECHNOLOGY TRANSFER GROUPS AND THEIR IMPACT ON TECHNOLOGY INNOVATION IN THE SUGAR AGROINDUSTRY IN THE CAUCA VALLEY, COLOMBIA

By

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KEYWORDS: Technology Transfer Groups,
Colombian Sugar Agro-Industry, Technology Innovation,
Characterisation of Productive Units, Dynamic Monitoring.

Abstract

THE PURPOSE of this study was to measure the impact of the technology transfer strategy of forming groups of cane producers known as Technology Transfer Groups (GTT – Spanish acronym) in the process of technological innovation in the sugarcane agroindustry in the Cauca Valley, Colombia. The GTTs prioritised their needs for technical information and then implemented a program for outreach and exchange of the best cultural practices based on various group communication methods. Two years after the program started, a dynamic process of monitoring technological innovation in the production units began; and the changes in the process of technology adoption were characterised over time, focusing on the factors that were most influential in the process. The monitoring, which was done with a representative sample of cane producers, found that the greater exchange of best practices among them led to their faster adoption and increased levels of technology adoption (cane varieties and agronomic practices), as well as the productivity of their production units. In addition, it created a culture of agricultural practices based on site-specific agriculture and strengthened the interactions, communication and integration among the producers, sugar mill professionals and researchers. The greater adoption of technology, product of CENICAÑA’s research, has led to a dynamic process of technological innovation in the sugar agro-industry as the new agricultural practices generate higher returns for the producers, sustainability and competitiveness.

Introduction

CENICAÑA is a private, non-profit corporation, founded in 1977 by the Association of Sugarcane Growers of Colombia (ASOCAÑA). Its mission is to contribute to the development of the national sugar sector by means of research, technology transfer and the supply of specialised services so that the sector is competitive and can play an outstanding role in socioeconomic improvement and in the conservation of a productive, pleasant and healthy environment in the sugarcane production zones.

In 1995, the principles of social marketing were gradually incorporated into the CENICAÑA research and technology transfer system, given the low rate of adoption of the new technologies by the sugarcane productive units, particularly in the Cauca River Valley.

The project ‘Study of the clients for CENICAÑA’s new technology’ was begun. A census was taken of the cane producers and their productive units, which served as a basis for breaking down the clients for the technologies in order to design transfer and technical communication strategies. Two groups were identified according to their level of technology adoption with five subgroups ordered by level of schooling and crop ownership (Isaacs et al., 2000). Then a
behavioural characterisation of the potential adopters was prepared, based on personal characteristics (psychological, sociological and socioeconomic) that were expected to influence the process of technology innovation (M.J. Marrón in Puyol et al., 1995; Isaacs et al., 2002).

In 2001, together with the publication of the third approximation of the agro-ecological zoning for growing sugarcane in the Cauca River Valley (Carbonell et al., 2001), CENICAÑA strengthened its site-specific agriculture (SSA) initiative.

This initiative focuses on adapting and applying research and technology transfer of specific agricultural technologies to specific crop sites with unique soil and climate characteristics, and physical and socioeconomic infrastructure.

Its objective is to optimise the levels of productivity and profitability within the framework of sustainable development.

To disseminate SSA and promote the use of improved cultural practices from the technical, economic, environmental and quality control standpoint, among others, the project ‘Technology transfer groups (GTTs)’ was designed to link the cane suppliers of 11 sugar mills from 2001–2006 (Isaacs and Uribe, 2002; CENICAÑA, 2009a).

The strategic methodology applied successfully by the National Institute of Agricultural and Livestock Research (INIA, Chile) and by the Regional Consortia of Agricultural Experimentation (CREA, Argentina) (Isaacs, 1999; CREA, 2009; INIA, 2009) was adapted.

At the 455 events (293 field days, 104 conferences, 53 workshop-courses and five technical study tours) that the GTT program held during this time, 112 innovative cane growers presented their experiences related to technological management in their productive units. These have been documented and can be consulted on www.cenicana.org.

The objective of this study was to evaluate the influence of the GTT program on the process of technology innovation of the Colombian sugar agro-industry during the period 2001–2008.

Materials and methods

The GTT program has five components:

**Formation of groups and characterisation of the productive units**

In each sugar mill, groups were formed with a maximum of 25 cane suppliers with productive units of similar agro-ecological characteristics. (CENICAÑA, 2008).

A workshop was held with each group to characterise the technologies used in their productive units prior to the GTT program and characterise them using reference indicators to evaluate their management of technology transfer.

The producers filled out a formal survey on technology adoption, socioeconomic characteristics and the physical infrastructure of the productive units under their charge (CENICAÑA, 2009b)

The groups included three different types of producers: PV-1: suppliers with limited innovation and low productivity; PV-2: intermediate in innovation and productivity; and PV-3: the most innovative and with high productivity (Table 1 and Figure 1).

In Figure 1, each isoline represents points of equal productivity in tonnes of sugar per hectare; it means the combination of tonnes of cane per hectare per sugar content (%). All in all, 23 GTTs were formed with 900 suppliers.

**Identification of priorities regarding the groups’ needs for technical information**

In participatory workshops with each GTT, the needs for the groups’ technical information were prioritised by CENICAÑA using a Vester Matrix based on the technological problems that the producers perceived as production constraints (Table 2).

A program of transfer events was prepared, using the communication media preferred by the producers for obtaining technical information: primarily field days and roundtable discussions.
Table 1—Application of Marrón's model explaining innovative behaviour (In: Puyol et al., 1995, p. 339) with producers in Groups PV-1, PV-2 and PV-3 in relation to the adoption of new technologies.

<table>
<thead>
<tr>
<th>Variables which characterise an innovating conduct</th>
<th>Grower type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PV-1</td>
</tr>
<tr>
<td><strong>Variables inherent in the innovation</strong></td>
<td></td>
</tr>
<tr>
<td>Economic yield</td>
<td>Yes</td>
</tr>
<tr>
<td>Compatibility with previous crop</td>
<td>Yes</td>
</tr>
<tr>
<td>Easy to farm</td>
<td>Yes</td>
</tr>
<tr>
<td>Possibility of prior experimentation</td>
<td>Yes</td>
</tr>
<tr>
<td>Immediate comparison of yield</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Variables relative to personal characteristics of potential adopters</strong></td>
<td></td>
</tr>
<tr>
<td>• Socioeconomic</td>
<td></td>
</tr>
<tr>
<td>Schooling</td>
<td>24% primary 76% secondary</td>
</tr>
<tr>
<td>Social status</td>
<td>Middle-low</td>
</tr>
<tr>
<td>Size of operation</td>
<td>Low Average 53 ha</td>
</tr>
<tr>
<td>Operations under producer-supplier regime</td>
<td>Yes</td>
</tr>
<tr>
<td>• Psychological</td>
<td></td>
</tr>
<tr>
<td>Decision-making autonomy</td>
<td>Yes</td>
</tr>
<tr>
<td>Fatalism</td>
<td>Median presence</td>
</tr>
<tr>
<td>Profit oriented</td>
<td>Yes</td>
</tr>
<tr>
<td>Openness to change</td>
<td>Low</td>
</tr>
<tr>
<td>Risk avoidance</td>
<td>High</td>
</tr>
<tr>
<td>Traditionalist, enterprising, innovator</td>
<td>Traditionalist</td>
</tr>
<tr>
<td>• Sociological</td>
<td></td>
</tr>
<tr>
<td>Family situation</td>
<td>Apparently without difficulties</td>
</tr>
<tr>
<td>Age</td>
<td>From 41 to 60 years old</td>
</tr>
<tr>
<td>• Farmers’ social behaviour</td>
<td></td>
</tr>
<tr>
<td>Localism, cosmopolitism</td>
<td>Localism</td>
</tr>
<tr>
<td>Social participation</td>
<td>Not affiliated to associations</td>
</tr>
<tr>
<td>Exposure to communication channels</td>
<td>Low-middle</td>
</tr>
<tr>
<td><strong>Structural variables</strong></td>
<td></td>
</tr>
<tr>
<td>Land adjustments</td>
<td>Middle</td>
</tr>
<tr>
<td>Water availability</td>
<td>Acceptable</td>
</tr>
<tr>
<td>Community</td>
<td>Conservative</td>
</tr>
<tr>
<td>Development economic</td>
<td>Low to middle</td>
</tr>
</tbody>
</table>

1. Procaña: Colombian Association of Sugarcane Producers and Suppliers
2. Asocaña: Association of Sugarcane Growers of Colombia
3. Tecnicaña: Colombian Association of Sugarcane Technician
Fig. 1—Crop production isolines for sugarcane producers and agro-ecological zone 11H3 (2004–2008).

Table 2—Prioritisation of producers’ needs for technical information on sugarcane in the Cauca Valley. GTT at the Manuelita Sugar Mill.

<table>
<thead>
<tr>
<th>Problem No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>Points</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>9</td>
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<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>0</td>
<td>10</td>
<td></td>
<td></td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
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<td>7</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

1. Waste management (Priority 1)
2. Water management (Priority 2)
3. Soil compaction (Priority 3)
4. Harvest
5. Ripeners
6. Varieties
7. Energy alternatives for well management
8. Soil management and cultural practices
9. Farm administration
10. Training of field staff

Program of events and their implementation

The field days, as the principal medium of group communication, were preferably held on the farm of the producer identified by the group as being the most innovative and progressive in the
technical topic to be addressed. The program usually included three presentations: (1) The host producer presented the best practices for the topic in question and the results obtained; (2) The technical expert of the sugar mill explained the best practices implemented by the sugar mill; (3) The expert researcher from CENICAÑA discussed the progress made in the related research, with emphasis on the practical results for the producer. Each presentation addressed the technical aspects (application and use of technology), economic factors (profitability of new vs. conventional technologies), environmental aspects (sustainability), and quality control (correct utilisation of the technology). Finally a roundtable discussion was organised to share experiences, define needs for technological R&D, and identify technologies that should be validated under the production conditions in the GTTs’ agro-ecological zones of influence. The producers’ observations, requests, suggestions and recommendations to CENICAÑA were recorded for feedback into the processes of research, technology transfer and the GTT program (Table 3).

Table 3—Example of the needs expressed by the GTT with the purpose of supporting technological management and innovation in the sugarcane productive units.

<table>
<thead>
<tr>
<th>TOPIC</th>
<th>Needs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water management</strong></td>
<td>Training of estate administrators and irrigation workers</td>
</tr>
<tr>
<td></td>
<td>Information on energy sources for operating deep wells</td>
</tr>
<tr>
<td></td>
<td>Development of Water Balance software (update)</td>
</tr>
<tr>
<td></td>
<td>Information on pulse, trickle and pivot irrigation; fertigation</td>
</tr>
<tr>
<td><strong>Varieties and nurseries</strong></td>
<td>New varieties according to agro-ecological zone</td>
</tr>
<tr>
<td></td>
<td>Information on technological packages by variety</td>
</tr>
<tr>
<td></td>
<td>Indicators for varieties with mechanised harvest</td>
</tr>
<tr>
<td></td>
<td>Economic information on varieties</td>
</tr>
<tr>
<td><strong>Varieties and nurseries</strong></td>
<td>New varieties according to agro-ecological zone</td>
</tr>
<tr>
<td></td>
<td>Information on fertilisation in green cane harvesting</td>
</tr>
<tr>
<td></td>
<td>Information on uses of chlorophyll meter and its practical utility</td>
</tr>
</tbody>
</table>

The proceedings of each event are published in CENICAÑA’s extranet for reference by registered users, who can also access the SSA information tools on line and consult structured databases that are regularly updated and designed to support the technical, economic and administrative decision-making in the productive units. The Web system also offers access to the library’s catalogues and publications, as well as to the bank of frequently asked questions and technological consultations, whereby the producer has the chance to interact with researchers and consult them about technical issues.

**Dynamic monitoring**

In order to measure the progress made in managing technology adoption, a process of systematic and participatory monitoring was carried out: first at two years after having begun the GTT program in each sugar mill and then at five years.

In this way, the progress in the adoption of the technologies in the short term was measured, and in the medium term the changes in the indicators of productivity and profitability of the productive units were evaluated, after which the impact of the communication strategy was determined. From 2001–2006, a total of 11 sugar mills were connected with the GTT program: Risaralda in 2001; Manueilita and Providencia in 2002; Castilla, Incauca, Mayagüez and Pichichí in 2003; Riopaila and Sancarlos in 2004; Cabaña and Carmelita in 2006. The monitoring analyses were done for the first eight mills.

The information was obtained by means of semi-structured interviews conducted by expert agronomists with a representative sample of the producer population, designed using simple random
sampling. The interviews were held in the productive units, using a guide for recording the current use of technology. The data were then recorded in a database created in Microsoft Excel©. The following analyses were performed:

- **Descriptive analyses** to synthesise the information and characterise the current use of the technologies through graphics, frequency distribution tables, indicators of central tendency and indicators of dispersion. The results obtained were broken down by producer; i.e. the cane provider or administrator of productive units with direct management of a sugar mill.
- **Multivariate analyses** for identifying possible associations between the characteristics of the adopters and non-adopters of the water balance methodology for programming crop irrigation schedules in the productive units.

These analyses were done with the SAS© statistical software v.9.1.3. They comprised:

- Multiple correspondence analysis in which the characteristics of the producers were associated on a Cartesian plane
- Analysis of conglomerates in which the characteristics of the associated producers were grouped in the multiple correspondence analysis, and segments of producers with similar characteristics and behaviours were created.

The results for each sugar mill were documented and then analysed with each GTT. For an example, consult Pino (2007).

**Results and discussion**

Examples are given of the results of the monitoring done in the productive units of cane suppliers participating in the GTT program in relation to the adoption of technologies such as cane varieties, SSA, water management, fertilisation and planting.

**Adoption of technology such as cane varieties**

In 2008, CENICAÑA varieties Colombia (CC) occupied 88% of the area planted with sugarcane in the Cauca River Valley, an increase of 40% with respect to 2001. In 2008, the most planted varieties were CC 85-92 (69%) and CC 84-75 (14%). Other new varieties in commercial validation trials have occupied 5% of the area since 2001 (Figures 2 and 3).

![Area harvested (% ha) vs Time (years)](image)

**Fig. 2**—CENICAÑA Colombia (CC) varieties in the Colombian sugar agro-industry from 2001–2006: Adoption of commercial varieties.

With respect to varietal adoption, the producers in the GTTs said that they decided to adopt a variety when it has:
• a high operating margin;
• sustainable production;
• productivity over 10 tonnes of cane per hectare per month (TCHM – Spanish acronym);
• production 10% higher with respect to the currently planted variety;
• results of commercial testing of 250 ha or more at their specific sugar mill.

Fig. 3—CENICAÑA Colombia (CC) varieties in the Colombian sugar agro-industry from 2001–2006: Semicommercial testing of varieties.

Adoption of the SSA approach for taking decisions about agronomic management

With the dissemination of the SSA approach, the number of cane suppliers that use the agro-ecological zoning developed by CENICAÑA to decide which cultural practices to use has increased by 51%; the cane suppliers that use it to decide which variety to plant has grown by 37%; and those who can identify the agro-ecological zones of influence in their productive units has increased by 15%. A total increment between sugar mills and cane suppliers of 33%, 21% and 8% to each technology.(Figure 4).

Fig 4—Adoption of the site-specific agriculture (SSA) approach for decision-making in the sugarcane crop by cane suppliers and sugar mills.
Adoption of agronomic management technologies with the SSA concept

The principal changes in the adoption of technology by the productive units of suppliers are summarised in Table 4. Some of them are commented on below.

Table 4—Changes in the adoption of technologies in the sugarcane production systems in the Cauca River Valley. Percent cane suppliers (GTTs per sugar mill) who confirmed their use of the technologies.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Changes in technology adoption based on percentage of cane suppliers that use them</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water management (irrigation and drainage)</td>
<td></td>
</tr>
<tr>
<td>Water balance</td>
<td>6</td>
</tr>
<tr>
<td>Alternate ridge irrigation</td>
<td>31</td>
</tr>
<tr>
<td>Gated PVC pipes</td>
<td>14</td>
</tr>
<tr>
<td>Surface drainage</td>
<td>–</td>
</tr>
<tr>
<td>Fertilisation</td>
<td></td>
</tr>
<tr>
<td>Soil analyses</td>
<td>96</td>
</tr>
<tr>
<td>CENICAÑA’s Chemistry Lab</td>
<td>4</td>
</tr>
<tr>
<td>Critical levels determined by CENICAÑA</td>
<td>15</td>
</tr>
<tr>
<td>Nitrogen: one application (no split applications)</td>
<td>17</td>
</tr>
<tr>
<td>Planting density</td>
<td></td>
</tr>
<tr>
<td>Distance of 1.65 m between furrows</td>
<td>3</td>
</tr>
<tr>
<td>Distance of 1.75 m between furrows</td>
<td>3</td>
</tr>
<tr>
<td>Distance of flag markers &gt;=12 m (planting)</td>
<td>–</td>
</tr>
</tbody>
</table>

Table 4 cont.
Water management

The monitoring of the irrigation methods used by the cane suppliers shows that the irrigation events are characterised by continuous furrow and alternate ridge applications with irrigation channels and siphon tubes, followed by continuous furrow applications and the use of gated PVC pipes, alternate ridge applications and gated PVC pipes, and finally sprinkler irrigation.

Water balance

The descriptive analysis indicates increases in the level of adoption of the water balance methodology for programming the irrigation for both the alternate ridge applications and the use of gated PVC pipes, as well as in infrastructure for surface drainage. The principal reasons for the change are related to the benefits obtained with the use of water balance software (Cenicaña© WB v.3.0), reflected in a decrease in the number of irrigations (from 1–3 fewer irrigations per cut), the reduction in production costs, and better organisation of the productive unit. Those who are not using the WB program said that they were unfamiliar with its management.

The first two dimensions of the multiple correspondence analysis explained 92.1% of the total variability; the first dimension (Dim1) explained 82.8% and the second dimension (Dim2) explained 9.3% of the variability.

Dim1 is determined by the adoption or not of the water balance program so that low values of this dimension are associated with producers who do not adopt the program and high values with producers who adopt it. This dimension also presents a direct association with the education level and with the productive unit size; low values of Dim1 are associated with low or medium education level and areas of productive units ≤ 500 hectares. High values of Dim1 are associated with high education level and areas of productive units > 500 hectares. Besides, producers with age ≤ 45 years are associated with high values of Dim1, and producers with age > 46 years with low values.

Given the poor explanation of the variability for Dim2, it is not easy to interpret. Nevertheless, it was considered in the conglomerate analysis.

The statistical technique of conglomerate analysis uses software SAS 9.1 identified the possible associations between the adoption of the water balance methodology and the following variables: utilisation of the WB v.3.0, the producer’s age and schooling; schooling of the field supervisor, net area in cane group, source of the data on rapidly available water (LARA – Spanish acronym), source of information about the WB program, training in the WB program, owning a computer, owning the land and type of legal status. These analyses included information on cane suppliers and professionals from the sugar mills.

Four groups of producers were formed with similar characteristics, and a behaviour based on the adoption of the water balance methodology and the cause-effect relation of the adoption was determined (Figure 5).

Producers with aversion to technological change (Group 1): Characterised by having primary or secondary education (Pprim, Psecu), over 55 years of age, productive units under 50 ha, field supervisor with primary education (Mprim), do not own a computer (Noc), have not been trained in the use of the WB software and did not acquire the WB program (Nocp, Not).

Producers no adopters (Group 2): Characterised by having a technical education (Ptec), ages from 46–55 years, productive units with areas from 51–500 ha, do not use the WB program (Nobh), have not determined the LARA data (Nd), and all of them are cane suppliers (Prov).

Producers with a potential for adoption (Group 3): Characterised by being under 35 years of age, with a professional education (Pprof), manage from 501–1000 ha, trained in the use of the WB software and did not acquire the WB program (Sicp, Not).

Producers adopters (Group 4): Characterised by administering areas over 100 ha, ages from 36–45 years, graduate education (Ppost), obtained the LARA data from a specific study of the farm
Ef, of CENICAÑA’s table (TCc) or from the sugar mill (Ing), have field supervisor with technical education (Mtec), productive units directly managed by the sugar mill (mdi), and use the WB program (Sibh).

**Alternate ridges**

Among the main reasons for using alternate ridge irrigation, the producers mention the limited availability of water, decreased production costs, and optimised use of the water resource.

**Fertilisation**

The use of soil analyses to define the plan for fertilising the crop increased, as well as sending the samples to CENICAÑA’s Chemistry Lab for that purpose. Despite those increases, there was a noteworthy decrease in the number of suppliers that use the critical levels of NPK determined in the research carried out by CENICAÑA. The most frequent reason for this was that they do not use CENICAÑA’s lab service and therefore do not receive the recommendations that are given together with the results of the analysis.

The level of adoption of nitrogen fertilisation (just one application, not split) increased in the GTTs at some sugar mills; while in others there were no important changes. Those who split the nitrogen application explained that the main reason for doing so was the type of soil that they manage (sandy) and also because it is a traditional practice. On the other hand, those who applied nitrogen just once stated that by not splitting it, they also decreased their production costs. They also have knowledge of the positive results that have been obtained in commercial validation trials.

**Planting**

With respect to planting distances, there was a growing tendency for the percentage of suppliers who made the decision to use a distance greater than 12 m. The reasons include decreased production costs due to the use of less seed and the credibility of the experimental results. Those who use planting distances less than 12 m expressed their fear of having to replant and the subsequent increase in production costs.

Regarding the distance between furrows, there was no well-defined tendency of change. The most frequently used distances are 1.65 m and 1.75 m. The reasons indicate that with these distances the crop is favoured during the harvest because there is less damage to the stools from the machinery. Those who used smaller distances between furrows were afraid that the production would decline.
Use of the Web site

CENICAÑA’s Web site plays an active role in its technology transfer process. It offers the cane producers information and documentation services, as well as interactive consulting tools to support crop-related decision-making. Since it was launched in November 2003, the number of users registered on the Web site has increased progressively, as well as the number of users that consult the proceedings of the GTT program based on the statistics recorded by the AWStats© software (Figures 6 and 7).

![Fig. 6—Number of users registered on <www.cenicana.org> from November 2003 to April 2009.](image)

Technology innovation, productivity and profitability

In 2007, CENICAÑA contracted the Foundation for Higher Education and Development (FEDESARROLLO) to conduct an evaluation in order to learn what was the economic return on its investment in research and technology development. It was estimated that the additional net benefits coming from the use of varieties CC 85-92 and CC 84-75 reach US$46 million per year as compared with the use of the other varieties (CENICAÑA, 2008).

![Fig. 7—Number of visits by users with a code to enter the pages containing the proceedings from GTT events on www.cenicana.org.](image)
In experiments to validate the technology with the cane producers' participation, it was found that the use of reduced practices such as reduced tillage, fewer risks in accordance with water balance, lower plant density (seed) and minimum dose of fertiliser according to soil analysis, among others and practices with an SSA focus were good strategies for reducing production costs and increasing the levels of profitability vis-à-vis the conventional practices (Isaacs et al., 2009a, 2009b).

With respect to reducing production costs, the technologies for water management stand out, the use of which have contributed to decreasing up to 50% of the volume of water applied per unit of area.

Conclusions

- The GTT program has proven to be an effective strategy for group communication with the sugarcane producers and has promoted technology innovation in the productive units planted with sugarcane in the Cauca River Valley.
- The GTTs have strengthened the relations and communication among producers, researchers and field professionals from the sugar mills, facilitating the exchange of information on the best cultural practices.
- The exchange of information that is promoted in the GTTs has contributed to strengthening the knowledge of the sugarcane producers with emphasis on SSA applied to crop management.
- The increased levels of adoption of the new technologies promoted by CENICAÑA have impacted on both the productivity and the profitability of the cane productive units.
- The GTTs have been an effective mechanism for providing feedback to CENICAÑA about the needs that the sugarcane producers in the Cauca River Valley have for technological R&D.

REFERENCES


GROUPES DE TRANSFERT DE TECHNOLOGIE ET LEURS INCIDENCES SUR L'INNOVATION TECHNOLOGIQUE DE L'AGRO-INDUSTRIE SUCRIERE DANS LE CAUCA VALLEE, COLOMBIE

Par

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Résumé

L'OBJECTIF de cette étude était de mesurer l'impact de la stratégie de transfert de technologie pour former des groupes de producteurs de canne appelés Groupes de Transfert de Technologie (GTT – acronyme espagnol) dans le processus d'innovation technologique dans l’agro-industrie de la canne à sucre dans la vallée du Cauca en Colombie. Les GTTs ont donné priorité à leurs besoins pour obtenir des informations techniques et ont ensuite mis en place un programme de sensibilisation et d'échange des meilleures pratiques culturelles selon différentes méthodes de communication du groupe. Deux ans après que le programme ait été lancé, un processus dynamique d'innovation technologique dans les unités de production a commencé; et les changements dans le processus d'adoption de la technologie ont été caractérisés au fil du temps, en se concentrant sur les facteurs les plus influents dans le processus. Le suivi qui a été effectué à partir d'un échantillon représentatif des producteurs de canne, a démontré que les échanges entre eux ont permis à une adoption plus rapide et à un niveau supérieur de technologie (variétés de canne à sucre et pratiques agronomiques), ainsi qu’une meilleure productivité de leurs unités de production. En plus de cela, les pratiques agricoles se sont améliorées, les interactions, la communication, l'intégration entre les producteurs, les techniciens d'usine et les chercheurs se sont renforcés. L'adoption de la technologie, produit de la recherche du CENICAÑA, a conduit à un processus dynamique de l'innovation technologique dans le secteur de l’agro-industrie sucrière, car les nouvelles pratiques agricoles génèrent plus de revenus pour les producteurs, et assurent la durabilité et la compétitivité.
GRUPOS DE TRANSFERENCIA DE TECNOLOGÍA Y SU IMPACTO EN LA INNOVACIÓN DE TECNOLOGÍA EN LA AGROINDUSTRIA AZUCARERA DEL VALLE DEL CAUCA, COLOMBIA

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PALABRAS CLAVE: Grupos de Transferencia de Tecnología, Agroindustria Azucarera Colombiana, Innovación de Tecnología, Caracterización de Unidades de Producción, Monitoreo Dinámico.

Resumen
El objetivo de este estudio fue la medición del impacto de una estrategia de transferencia de tecnología basada en la formación de grupos de productores de caña denominados Grupos de Transferencia de Tecnología (GTT) en el proceso de innovación tecnológica en la agroindustria azucarera del Valle del Cauca en Colombia. Los GTTs priorizaron sus necesidades de información técnica y luego implementaron un programa para conseguir e intercambiar las mejores prácticas culturales, basados en varios métodos de comunicación de grupo. Dos años después de haber iniciado el programa, empezó un proceso dinámico de monitoreo de innovaciones tecnológicas en las unidades de producción; y los cambios en el proceso de adopción de tecnologías fueron caracterizados en el tiempo, enfocados en los factores que influenciaron más el proceso. En el monitoreo, que fue realizado con una muestra representativa de los productores de caña, se encontró que el mayor intercambio de las mejores prácticas entre ellos, condujo a la adopción más rápida y al incremento de los niveles de adopción de tecnologías (variedades de caña y prácticas agronómicas), así como la productividad en sus unidades de producción. Adicionalmente, creó una cultura de prácticas agrícolas basada en agricultura de sitios específicos y fortaleció las interacciones, comunicación e integración entre productores, profesionales de los ingenios e investigadores. La mayor adopción de tecnología, producto de la investigación de CENICAÑA, ha llevado a un proceso dinámico de innovación tecnológica en la agroindustria azucarera mientras las nuevas prácticas agrícolas generan retornos más altos para los productores, sostenibilidad y competitividad.
ECONOMIC BENEFITS OF RESEARCH:
MEASURING AND REPORTING

By

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KEYWORDS: Capital Budgets, Economics, Returns, Technology Transfer, Funding.

Abstract

AT THE ISSCT Management Commission Workshop in Townsville, Australia in May 2008, it was reported that, to a larger or lesser degree in most sugarcane producing countries, a ‘disconnect’ exists between research centres and their stakeholders. One reason for such a ‘disconnect’ is that research centres in many industries have already largely maximised productivity potential through cane variety breeding programs but stakeholders are not convinced of this, resulting in incongruent expectations. Another possible reason for the ‘disconnect’ is because productivity improvements are blurred by varying agro-climatic conditions and management practices. It has been suggested that research centres should better employ economic benchmarks to enable sugarcane growers to easily rank different research outcomes that compete for limited on-farm capital and management time. For non-financial experts, capital budgeting can be intimidating but spreadsheets take care of the complex mathematics and an economist or financial expert can be employed to source and disseminate generic costs. The capital budgeting methods described and adapted in this paper for the R&D context provide a powerful marketing tool for R&D outcomes in terms of attracting research funding and enhancing technology transfer to larger sugarcane growing firms in particular. Sugarcane farming is a business and research centres are increasingly required to communicate in the ‘language’ of business, notwithstanding the other environmental and social aspects of sustainable triple bottom line reporting. In an increasingly competitive global environment, this shift towards an improved understanding of economics is appropriate to all scales of sugarcane agriculture.

Introduction

At the ISSCT Management Commission Workshop in Townsville, Australia in May 2008, it was reported that, to a larger or lesser degree in most sugarcane producing countries, a ‘disconnect’ exists between research centres and their stakeholders (Wynne et al., 2008a). One reason for such a ‘disconnect’ is that research centres in many industries have already largely maximised productivity potential through cane variety breeding programs but stakeholders are not convinced of this, resulting in incongruent expectations. Breeding programs are indeed synonymous with maximising productivity potential and, although this rate of productivity increase has ‘slowed’ within commercial agriculture in recent times due to limitations associated with economic, environmental and management factors, active breeding programs must continue to ensure pests, disease, climate change, etc do not compromise productivity potential going forward and to create new economic opportunities through new products (e.g. energy cane) and farming systems (e.g. sustainably...
reducing input costs). This implies that relatively static productivity improvement benchmarks such as tonnes cane/sugar per hectare do not necessarily demonstrate that research and development (R&D) is ineffective; on the contrary, it may demonstrate its importance in preventing productivity declines.

Another possible reason for the ‘disconnect’ is because productivity improvements are blurred by varying agro-climatic conditions and management practices (Wynne et al., 2008b). Technology transfer plays an important role in facilitating the effective adoption of appropriate management practices for different agro-climatic conditions. Therefore, one of the technology transfer challenges is to convince industry participants of the economic value that will be derived from the implementation of a research outcome. Wynne et al. (2008a) suggest that research centres should better employ economic benchmarks to enable industry participants to easily rank different research outcomes that compete for limited on-farm capital and management time. This use of ‘business language’ should also aid research centres to compete more aggressively for investment funding for their future research programs; traditional physical benchmarks such as tonnes cane/sugar per hectare are less effective. The objective of this paper is to assist in providing this language; a glossary of the main economic terms used is presented at the end of the paper. While recognising the importance of environmental and social aspects of sustainable triple bottom line reporting (Christiansen, 2004), this paper will only explore the third economic component.

**Economic benchmarks for end users of R&D outcomes**

The underlying objective function of any sugarcane grower is to make a sustainable and preferably competitive economic return on their limited land, capital and management time. Increasing tonnes cane per hectare or sucrose percent cane are ‘derivatives’ of this underlying economic objective function. Therefore, ranking independent and/or mutually exclusive R&D outcomes in terms of economic worth, subject to environmental and social safeguards, should facilitate decision making and enhance technology transfer.

Governments typically evaluate large public sector projects in terms of the public's willingness to pay for them (benefits) or willingness to avoid them (costs), expressed in the form of a cost-benefit ratio. This is effectively achieved by listing all parties affected by an intervention where a monetary value or ‘welfare’ effect is assigned to each party. This welfare approach is not suited to the business environment of a sugarcane grower; capital budgeting techniques employed by business are more appropriate because they are aligned to optimising economic returns to limited land, capital and management time and therefore technically more robust. Capital budgeting techniques are well documented in the literature, where Brigham and Ehrhardt (2005) is the primary source in this paper. These capital budgeting techniques are explored with the view of applying or adapting them as economic benchmarks for R&D outcomes.

**Determining relevant cash flows**

Capital budgeting decisions are based on ‘free’ cash flows for the entire business, which is the cash flow generated by an economic activity that is available for distribution to investors. An accepted definition of incremental free cash flow for a specific business entity is as follows:

\[
\text{Incremental free cash flow} = \text{EBIT}^1 (1-\text{Tax}) + \text{Depreciation} - \text{Gross fixed asset expenditure} - \text{Change in net operating working capital}
\]

If an R&D outcome were to fully replace an existing on-farm operation, the cash flow difference between the existing and the new constitute the incremental free cash flow of this decision. Consequently, only the incremental cash flows pertinent to the R&D outcome are relevant; all other cash flows associated with other business activities cancel each other out. However, externalities associated with the adoption of an R&D outcome must be included in the

---

1 EBIT means earnings before interest and tax but inclusive of depreciation and amortisation.
incremental free cash flow calculation, whereby the earnings or cost structure of an existing operation might be enhanced or reduced; *i.e.* the net financial effect of the R&D outcome. Similarly, ‘opportunity costs’ must also be included as incremental free cash flows. This could be the market related cash flow that could be generated from an existing asset if it were made redundant by the adoption of the R&D outcome in question or the incremental free cash flows foregone if an existing asset becomes underutilised. The ‘opportunity cost’ approach is also a helpful tool in quantifying the value of costs and benefits that are difficult to otherwise express in financial terms.

Different businesses have different mixes of debt and equity capital (financial gearing) that have different tax implications, attracting different tax rates and possibly different tax laws that may require specialist skills. Furthermore, different businesses have different exposures to financial gearing or amortisation costs as well as working capital requirements. In instances where the implementation of an R&D outcome does not constitute a significant change to the existing financial status of a business, it can be assumed that tax implications and working capital requirements remain largely unaffected. It can also be assumed that 100% equity capital is used to finance fixed asset expenditure associated with the R&D outcome; *i.e.* amortisation costs are zero.

Consequently, the incremental free cash flow definition can be modified to cater for benchmarking R&D outcomes as follows:

\[
\text{Incremental free cash flow} = \text{EBITDA} - \text{Fixed asset expenditure}
\]

The challenges that remain are associated with qualifying fixed asset expenditure that will be incurred by a grower implementing the R&D outcome. A ‘sunk cost’ is fixed asset expenditure that has already been incurred and hence is not an incremental free cash flow and should therefore be excluded from the analysis. Conversely, the market value of an asset after its useful life, or ‘salvage value’, must be included. In terms of the incremental free cash flow timing, it is usually assumed that these occur at the end of each planning period (months or years). Where specialist accounting or economic skills are scarce, as in the scientific realms of research centres, this simplified and standardised approach to determining ‘generic’ incremental free cash flows has merit. Thereafter, adaptations can be made by industry participants or their agents to reflect ‘specific’ business entity operating environments.

**Determining relevant discount rates (finance costs)**

Incremental free cash flows arising from the implementation of an R&D outcome will accrue over a period of time into the future and because a dollar in hand today is worth more than a dollar received in future due to the interest it can earn. Future values (FV), therefore, need to be discounted to a present value (PV), which can easily be computed using a financial calculator or spreadsheet with the following underlying equation, where ‘r’ is the annual discount rate and ‘n’ the time period in years:

\[
PV = \frac{FV}{(1+r)^n}
\]

Inflation complicates matters because inflation erodes FVs; *i.e.* FVs are understated if ‘today’s’ values are used as a proxy for FVs. Therefore, in the presence of inflation, FVs must either be adjusted by an inflation factor or the annual discount rate (r) must be adjusted by an

---

2 In practice, most growers will utilise some debt financing but the extent is widely variable. The standardised 100% equity funding approach is both simple and reflective of the full value of the R&D outcome.

3 EBITDA means earnings before interest, tax, depreciation and amortisation; *i.e.* income generated by the R&D outcome less operating costs incurred by the R&D outcome, excluding depreciation and amortisation associated with the R&D outcome.
inflation factor. The latter approach is appropriate if it is assumed that a similar and consistent inflation factor will apply to all FVs and, because it is simple and robust, it is the preferred approach for research centres.

A business’s weighted average cost of capital (WACC) is the preferred annual discount rate but this varies between businesses and, therefore, from a generic benchmarking perspective, it is proposed that the national prime lending rate⁴ be used as the grower’s proxy annual discount rate (which is termed the nominal annual discount rate \( r_n \); i.e. before inflation is accounted for). A producer related inflation factor \( i \) is then used to adjust the nominal annual discount rate \( r_n \) to a real annual discount rate \( r_r \) as illustrated below, whereby FVs are expressed in ‘today’s’ nominal values (i.e. \( FV_n \) before inflation is accounted for):

\[
PV = \frac{FV_n}{(1 + r_r)^n} \text{ where } (1 + r_r) = \left(1 + \frac{r_n}{1+i}\right)
\]

**Discounted Payback Period (DPP)**

The simplest capital budgeting method is the ‘Discounted Payback Period’, defined as the expected number of years required by the grower to recover the initial capital investment, which is expressed as follows and illustrated in Table 1:

Discounted payback period = year before full recovery + \( \frac{\text{Unrecovered discounted cost in that year}}{\text{Discounted cash flow in subsequent year}} \)

<table>
<thead>
<tr>
<th>Annual Real Discount Rate ( (r_i) ) =</th>
<th>5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period (years) =</td>
<td>0</td>
</tr>
<tr>
<td>Undiscounted Nominal Cash Flow =</td>
<td>-$1,000.00</td>
</tr>
<tr>
<td>Discounted NCF =</td>
<td>-$1,000.00</td>
</tr>
<tr>
<td>Cumulative Cash Flow =</td>
<td>-$1,000.00</td>
</tr>
<tr>
<td>Year before full recovery =</td>
<td>2</td>
</tr>
<tr>
<td>Unrecovered cost in above year =</td>
<td>$70.29</td>
</tr>
<tr>
<td>Cash flow during subsequent year =</td>
<td>$259.15</td>
</tr>
<tr>
<td>Pay back period =</td>
<td>2.27</td>
</tr>
</tbody>
</table>

R&D outcomes with shorter payback periods are preferred. This easy to understand ‘breakeven’ benchmark is also indicative of the R&D outcome’s liquidity, providing a helpful perspective of associated risk. Its downfall, however, is that no cognisance is given to neither cash flows received after the payback period nor the economic life of the R&D outcome.

**Net Present Value (NPV)**

The ‘Net Present Value’ method takes cognisance of all cash flows, which is expressed as follows and illustrated in Table 1 (assumes the R&D outcome has an economic life of four years).

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⁴ Benchmarking research centres across international borders is complicated by exchange rate differentials. However, exchange rates, among other drivers, are influenced by nominal national prime lending rates. Therefore, if the use of nominal national prime lending rates becomes standard international practice for research centres, the international benchmarking of research centres becomes more meaningful.
Effectively, a NPV of zero means that the associated cash flows of the R&D outcome are sufficient to repay the initial capital investment over the expected life to the project. A positive NPV means the grower receives an economic return; i.e. wealth is created. NPV is arguably the best measure of absolute wealth creation but is unhelpful when R&D outcomes with varying capital investment requirements and unequal lives need to be compared and/or comparisons made to the opportunity cost of capital such as interest rates and/or competing off-farm investments.

**Profitability Index (PI)**

The ‘Profitability Index’ facilitates the comparison of R&D outcomes with varying capital investment requirements because it calculates the present value per dollar of initial cost, which is expressed as follows and illustrated in Table 2.

\[
PI = \frac{PV\text{ of future cash flows}}{Initial\ cost} = \frac{\sum_{t=0}^{n} \frac{CF_t}{(1 + r)^t}}{CF_0}
\]

**Table 2—Profitability Index example.**

<table>
<thead>
<tr>
<th>Annual Real Discount Rate ((r)) =</th>
<th>5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period (years) =</td>
<td>0</td>
</tr>
<tr>
<td>Undiscounted Nominal Cash Flow =</td>
<td>-$1,000.00</td>
</tr>
<tr>
<td>NPV Period 1 =</td>
<td>$476.19</td>
</tr>
<tr>
<td>NPV Period 2 =</td>
<td>$453.51</td>
</tr>
<tr>
<td>NPV Period 3 =</td>
<td>$259.15</td>
</tr>
<tr>
<td>NPV Period 4 =</td>
<td>$246.81</td>
</tr>
<tr>
<td>Total NPV (excl initial outlay) =</td>
<td>$1,435.67</td>
</tr>
<tr>
<td>Profitability Index =</td>
<td>1.44</td>
</tr>
</tbody>
</table>

A ‘breakeven’ R&D outcome will have a PI of 1 and the higher the PI, the more attractive the R&D outcome becomes.

Using the PI approach to compare R&D outcomes with unequal lives or with the opportunity cost of capital, however, remains problematic.

**Internal Rate of Return (IRR)**

The ‘Internal Rate of Return’ is defined as the discount rate that equates the present value of the R&D outcomes future cash flows and the initial capital investment.

The IRR is the discount rate where the NPV is zero, which is expressed as follows and illustrated in Table 3.
PV (investment costs) = PV (cash flows) OR NPV = 0 = \sum_{t=0}^{n} \frac{CF_t}{(1 + IRR)^t}

Table 3—Internal Rate of Return example.

<table>
<thead>
<tr>
<th>Annual Real Discount Rate (r) =</th>
<th>5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period (years) = 0 1 2 3 4</td>
<td></td>
</tr>
<tr>
<td>Undiscounted Nominal Cash Flow</td>
<td>-$1,000.00 $500.00 $500.00 $300.00 $300.00</td>
</tr>
<tr>
<td>NPV Period 1 =</td>
<td></td>
</tr>
<tr>
<td>NPV Period 2 =</td>
<td></td>
</tr>
<tr>
<td>NPV Period 3 =</td>
<td></td>
</tr>
<tr>
<td>NPV Period 4 =</td>
<td></td>
</tr>
<tr>
<td>Total NPV (incl initial outlay) = $0.00</td>
<td></td>
</tr>
<tr>
<td>Internal Rate of Return = 24.8%</td>
<td></td>
</tr>
</tbody>
</table>

If the IRR is greater than the grower’s debt interest rate, the grower is creating wealth and the adoption of the R&D outcome is considered beneficial. In theory, the IRR method solves the problems of comparing R&D outcomes with unequal lives and with the opportunity cost of capital. Unfortunately, the IRR method incorrectly assumes that all cash flows can be reinvested at the IRR rate, which means that projects with varying cash flows cannot be objectively compared; which includes R&D outcomes of unequal lives and/or with varying opportunity cost of capital.

**Modified Internal Rate of Return (MIRR)**

The ‘Modified Internal Rate of Return’ addresses the shortcomings of the IRR method by calculating the terminal value of each of the future cash flows using a known real discount rate and then solving for the discount rate that equates the present value of the combined terminal values with the initial capital investment. This definition is expressed as follows and illustrated in Table 4.

PV (investment costs) = PV (terminal cash flow value) OR NPV = 0 = \sum_{t=0}^{n} \frac{CF_t (1 + r_t)^{n-t}}{(1 + MIRR)^t}

Table 4—Modified Internal Rate of Return example.

<table>
<thead>
<tr>
<th>Annual Real Discount Rate (r) =</th>
<th>5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period (years) = 0 1 2 3 4</td>
<td></td>
</tr>
<tr>
<td>Undiscounted Nominal Cash Flow</td>
<td>-$1,000.00 $500.00 $500.00 $300.00 $300.00</td>
</tr>
<tr>
<td>Terminal Value Period 4 =</td>
<td>@ (1+r_r) $300.00</td>
</tr>
<tr>
<td>Terminal Value Period 3 =</td>
<td>@ (1+r_r) $315.00</td>
</tr>
<tr>
<td>Terminal Value Period 2 =</td>
<td>@ (1+r_r) $551.25</td>
</tr>
<tr>
<td>Total NPV (incl initial outlay) = $0.00</td>
<td></td>
</tr>
<tr>
<td>Internal Rate of Return = 14.9%</td>
<td></td>
</tr>
</tbody>
</table>

There are several alternative definitions of MIRR; the differences primarily relate to how positive and negative cash flows are compounded. Most spreadsheets have a MIRR function that accommodates all options but, as most growers are indebted, it can be safely assumed that reinvestment is at the cost of capital or real national prime lending rate (r_r); i.e. positive and negative cash flows are compounded using the same discount rate. This avoids unnecessary financial complexity in the R&D context. Essentially, the MIRR method provides a standardised measure to compare different R&D outcomes of unequal economic lives as well as alternative investment options; i.e. if the MIRR is greater than the real national prime lending rate (r_r), the R&D outcome creates more wealth than a risk free investment at the bank. What the MIRR does not achieve is provide an indication of the total value add of the potential R&D outcome.

**Recommended capital budgeting approach for R&D outcomes**
Given that spreadsheets take care of the complex mathematics associated with capital budgeting with relative ease and that no single approach provides a panacea, it is recommended that three capital budgeting approaches be routinely computed for each R&D outcome and communicated with industry participants in the context of the unique insights each approach provides as described in Table 5. Other capital budgeting techniques can be ignored for reasons already given and/or because the insights they provide are already provided by those mentioned in Table 5.

Table 5—Recommended capital budgeting approach for R&D outcomes.

<table>
<thead>
<tr>
<th>Method</th>
<th>Motivation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discounted Payback Period</td>
<td>Provides a measure of the R&amp;D outcomes initial liquidity and associated risk profile.</td>
</tr>
<tr>
<td>Net Present Value (economic life)</td>
<td>Provides a measure of absolute wealth creation, which needs to be contextualised with the economic life.</td>
</tr>
<tr>
<td>Modified Internal Rate of Return</td>
<td>Provides a standardised measure enabling different R&amp;D outcomes with different economic lives and cash flows to be compared as well as alternative investment options.</td>
</tr>
</tbody>
</table>

In a study of 392 Chief Financial Officers employed by non-agricultural firms (Graham and Harvey, 2001), 74.9% and 75.7% evaluated new projects using the Net Present Value and Internal Rate of Return respectively, with 56.7% using the payback approach; i.e. most firms use more than one evaluation approach. This survey also found that smaller firms were more likely to rely on the payback approach, while larger firms were more likely to rely on the Net Present Value and Internal Rate of Return, which is consistent with earlier studies by Brierman (1993) and Walker et al. (1993). The three most cited reasons why smaller firms focus on the payback approach are:

(1) smaller firms preoccupation with liquidity, which is best indicated by payback;
(2) a lack of familiarity with capital budgeting techniques; and
(3) a belief that small projects do not warrant the effort of a capital budget.

Large sugarcane growing firms, such as those found in South and Central America, may already use capital budgeting techniques to evaluate new projects. Such practices are expected to be less common in Australia and South Africa where cane growing firms are much smaller and absent altogether from industries that are populated by very small firms like India and Thailand. From a research centre perspective, the use of capital budgeting as an extension and marketing tool is expected to have the highest uptake and to be most effective among larger firms. This does not negate the use of capital budgeting at research centres that service smaller firms because capital budgeting provides:

(1) an invaluable tool for the internal evaluation of projects; and
(2) improves stakeholders’ understanding of economic terms and business sense.

Research centres, therefore, need to tailor their initial capital budgeting approach to their immediate circumstances. Striving for economic perfection at the outset will be a misguided approach. Instituting an economic focus or ‘culture’ is as much about change management as it is about economics.

**Economic benchmarks for research centres generating R&D outcomes**

Researchers generally have limited exposure to economics and therefore may be reticent to employ economic benchmarks, particularly if this approach is burdensome. Ensuring ‘buy-in’ from researchers may require the compilation of generic costing sheets that are updated and disseminated for researchers to use in their own R&D outcome capital budgets. Training would also need to be provided to maintain robust and reliable results.
The most meaningful incentive to employ economic benchmarks, however, is for researchers to demonstrate the value of their research, particularly to attract funding resources. This is also true for the research centre as a whole, creating an incentive for the research centre to consolidate all its independent capital budgeting models. This has the advantage of facilitating a measure of standardisation and providing a ‘checking step’ for all the capital budgets for independent R&D outcomes. These composite measures for the research centre are expressed as follows (superscripts RC and RO stand for research centre and research outcome respectively):

\[
\text{Weighted average } \text{DPP}^{\text{RC}} = \frac{\sum_{i=1}^{n} \text{DPP}_{i}^{\text{RO}} \cdot \text{NPV}_{i}^{\text{RO}}}{\sum_{i=1}^{n} \text{NPV}_{i}^{\text{RO}}}
\]

\[
\text{Weighted average } \text{MIRR}^{\text{RC}} = \frac{\sum_{i=1}^{n} \text{MIRR}_{i}^{\text{RO}} \cdot \text{NPV}_{i}^{\text{RO}}}{\sum_{i=1}^{n} \text{NPV}_{i}^{\text{RO}}}
\]

A research centre cannot sum the NPV of each research outcome to determine its absolute wealth creation because there are often numerous parallel research outcomes that would result in double counting. The annual budget of the research centre provides an indication of the scale of the research centre and its associated operations. In terms of a research centre’s attention to liquidity, risk and return on investment, the weighted average DPP\textsuperscript{RC} and the weighted average MIRR\textsuperscript{RC} provide a clear enough picture.

**Implementation**

Cost estimates are the basis of capital budgeting and therefore need to be reliable. Research centres that embrace capital budgeting therefore must also implement measures to collate cost estimates. There are numerous ways this can be done, which include:

1. subsidising a book keeping service for farmers from which costs can be extracted;
2. forging relationships with farmers and their accountants to share costs on a confidential basis;
3. conduct statistically sound economic surveys; and
4. establish costs from a zero base by contacting market participants directly.

With the advent of computers and increasing uptake of computerised accounting, all of these approaches are becoming more robust. In practice, a combination of approaches is usually required, the emphasis being determined by local conditions.

An *ex-ante* evaluation should be conducted prior to or at the start of a project to aid in project planning, but these often suffer from a dearth of information and potential biases in data and analyses, examples of which include:

1. reliance on past projects that may differ markedly in function, size and certainty in the skill levels of the researchers;
2. reliance on crude heuristics (‘rules of thumb’) to estimate free cash flows, particularly of intangible elements; and
3. an inability to dispel biases (often unconscious) of researchers who often have a vested interest in a ‘go ahead’ outcome or a ‘think positive’ psychological tendency.

*Ex-post* evaluations of R&D outcomes, therefore, are equally important; *i.e.* economic
evaluations after implementation to test assumptions and accuracy.

An example best illustrates how the economic benchmarks described can be employed by a research centre: A research centre breeds and develops cane variety A followed by cane variety B. When variety B is released, sugarcane growers need to decide whether to continue with variety A or replant with variety B, where the yields are 100 and 90 tonnes cane per hectare respectively and ratooning ability of 3 and 4 years respectively, as illustrated in Table 6.

At first glance, a grower might be tempted to retain variety A because of its higher annual undiscounted nominal cash flow and shorter discounted payback period arising from its higher yield.

However, once the ratooning cycles have been accommodated, variety B shows greater economic promise with a higher net present value and modified internal rate of return.

The grower might nevertheless retain variety A for environmental reasons such as susceptibility to pests and diseases (although the researcher could discount the yield to accommodate this impact in conjunction with probability scenarios) or social reasons whereby a contractor that undertakes both harvesting and planting for the grower threatens to withdraw completely if the planting schedule is altered.

The composite measures for the research centre’s breeding program are also presented.

Table 6—Illustrative example of a sugarcane grower selecting a cane variety.

<table>
<thead>
<tr>
<th>Assumptions</th>
<th>Variety A</th>
<th>Variety B</th>
<th>RC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual real discount rate (%)</td>
<td>5.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cane price (per tonne of cane)</td>
<td>$25.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planting cost (per hectare)</td>
<td>$1700.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ratoon cost (per hectare)</td>
<td>$900.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harvesting costs (per tonne of cane)</td>
<td>$6.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variables</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of ratoons (economic life)</td>
<td>3.00</td>
<td>4.00</td>
<td></td>
</tr>
<tr>
<td>Annual harvest yield (tonnes cane per hectare)</td>
<td>100.00</td>
<td>90.00</td>
<td></td>
</tr>
<tr>
<td>Annual undiscounted nominal cash flow</td>
<td>$1000.00</td>
<td>$810.00</td>
<td></td>
</tr>
<tr>
<td>Results</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discounted Payback Period (DPP)</td>
<td>1.82</td>
<td>2.28</td>
<td>2.06</td>
</tr>
<tr>
<td>Net Present Value (NPV)</td>
<td>$1023.25</td>
<td>$1172.22</td>
<td></td>
</tr>
<tr>
<td>Modified Internal Rate of Return (MIRK)</td>
<td>18.1%</td>
<td>19.7%</td>
<td>19.0%</td>
</tr>
</tbody>
</table>

Discussion and conclusion

For non-financial experts, capital budgeting can be intimidating. However, given that spreadsheets take care of the complex mathematics and an economist or financial expert can be employed to source and disseminate generic costs, the skill of constructing a capital budget can be developed on a broad scale within a research centre, particularly if economics becomes engrained in the organisation’s culture. Such a culture should be the end goal of research centres but this can only be achieved incrementally over a period of time; striving for economic perfection is an unrealistic goal. However, researchers must be urged to identify and qualitatively explain their capital budgeting results because the results of capital budgeting are only as good as their assumptions and inputs.

Every effort must be made to ensure that data inputs have integrity. In this regard, it is recommended that updated generic costing sheets are regularly disseminated to researchers to input
into their own capital budgets, that random capital budgeting audits are conducted and that training is provided to maintain robust and reliable results on a consistent basis.

The capital budgeting methods described and adapted in this paper for the R&D context provide a powerful marketing tool for R&D outcomes in terms of attracting research funding and enhancing technology transfer to larger sugarcane growing firms in particular.

Sugarcane farming is a business and research centres are increasingly required to communicate in the ‘language’ of business, not withstanding the other environmental and social aspects of sustainable triple bottom line reporting.

In an increasingly competitive global environment, this shift towards an improved understanding of economics is appropriate to all scales of sugarcane agriculture.

ECONOMIC GLOSSARY

**Amortisation**—a loan repaid in fixed equal periodic amounts that comprise principal and interest components.

**Cash flow**—all the cash transactions relating to a firm that occur during a defined period.

**Discounting**—the process of finding the present value of a single payment or series of payments.

**Equity capital**—financial contribution by the owners of a firm as opposed to debt finance.

**Externalities**—an indirect consequence of a project, where prices do not reflect the full costs or benefits in production or consumption of a product or service.

**Liquidity**—refers to a firm’s cash position and its ability to make maturing payments. A liquid asset can be sold quickly and converted to cash.

**National prime lending rate**—the average interest rate payable to banks for debt finance on a project of average risk.

**Nominal**—the effects of inflation are not accounted for.

**Opportunity cost**—a cash flow that a firm must forego to accept a project, or alternatively the next best cash flow that a firm will accrue in the absence of a project.

**Producer related inflation**—the loss of purchasing power over time calculated using a basket of goods representative of producers’ inputs. Consumer related inflation is associated with a basket of goods representative of consumers’ purchases.

**Real**—the effects of inflation are accounted for.

**Terminal value**—at the end of a project, assets may have a terminal or residual value that can be realised.

REFERENCES


GAIN ECONOMIQUE DE LA RECHERCHE:
MESURE ET RAPPORT

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MOTS CLÉS: Budgets Capitaux, Rentabilité, Retours sur Investissements, Transfert de Technologie, Financement.

Resume

A L’ATELIER de Gestion de l’ISSCT tenu en mai 2008 à Townsville, Australie, il fut rapporté que dans plus ou moins tous les pays producteurs de canne à sucre, une incompréhension existait entre les centres de recherches et les producteurs. Une des raisons de cette incompréhension est que la recherche avait déjà optimisé la productivité à travers les programmes de croisement variétal tandis que les producteurs n’étaient pas convaincus de cela et s’attendaient à de meilleurs résultats. Une autre raison de cette incompréhension, est le fait que les conditions agro climatiques et les pratiques culturales masquent souvent le gain de productivité. Il a été suggéré que les centres de recherches fassent des études économiques pour permettre aux producteurs de cannes de comparer les différents projets de recherche qui sont en compétition. Pour les experts non financiers, les budgets capitaux peuvent être décourageants, mais les chiffres peuvent être expliqués et un économiste ou un expert financier peut être employé pour identifier et ventiler les coûts des projets. Les méthodes de Budgets Capitaux décrits et adaptés dans cette présentation dans le contexte de R & D nous donne un puissant outil de marketing pour attirer des fonds pour la Recherche et accélérer le transfert de technologie au gros producteur de cannes en particulier. L’exportation de canne à sucre est un business, et les centres de recherches doivent aujourd’hui communiquer dans des termes financiers, sans oublier les autres aspects sociaux et environnementaux. Avec une augmentation de compétitivité dans l’environnement global, ce changement vers une amélioration de la rentabilité est approprié à tous les niveaux de la culture de la canne.
BENEFICIOS ECONÓMICOS DE LA INVESTIGACIÓN: MIDIENDO Y REPORTANDO

Por

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PALABRAS CLAVE: Presupuestos de Capital, Economía, Retornos, Transferencia de Tecnología, Financiamiento.

Resumen

EN EL TALLER de la Comisión de Gerencia de ISSCT que se llevó a cabo en Townsville, Australia en mayo de 2008, se reportó que en mayor o menor grado en la mayoría de países productores de caña de azúcar existe una ‘desconexión’ entre los centros de investigación y sus actores principales. Una de las razones para esta ‘desconexión’ es que los centros de investigación en varias industrias han maximizado el potencial de productividad a través de los programas de mejoramiento de variedades, pero los actores principales no están convencidos de esto, resultando en incongruencias en sus expectativas. Otra posible razón para la ‘desconexión’ es que las mejoras en productividad son opacadas por varias condiciones agro-climáticas y por algunas prácticas gerenciales. Se ha sugerido que los centros de investigación mejor deberían emplear comparativos económicos para permitir que los productores de caña puedan calificar los distintos productos de la investigación que compiten por el limitado capital y el tiempo gerencial del productor. Para los no-expertos en finanzas, el presupuesto de capital puede ser intimidante pero las hojas electrónicas se encargan de la matemática compleja y un experto en finanzas o en economía puede contratarse para direccionar o diseminar los costos genéricos. Los métodos de presupuesto de capitales descritos y adaptados en este trabajo para el contexto de I+D proveen una herramienta poderosa para el mercadeo de los productos de I+D, en términos de atraer financiamiento para investigación y el mejoramiento de la transferencia de tecnología particularmente para industrias azucareras más grandes y en crecimiento. La producción de caña de azúcar es un negocio y cada vez se requiere más que los centros de investigación se comuniquen en el ‘lenguaje’ de los negocios, sin dejar de lado los otros aspectos de los reportes de sostenibilidad o sea los ambientales y sociales. En un ambiente global en el que crece la competitividad, este giro que procura entender mejor la economía es apropiado en todas las escalas de la agricultura de la caña.
RESEARCH AND EXTENSION NEEDS TO MITIGATE CONSTRAINTS LIMITING THE PRODUCTIVITY OF SMALL-SCALE SUGARCANE FARMERS IN MAURITIUS

By

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KEYWORDS: Small-Scale Farmers, Improved Productivity, Competitiveness, Sustainability.

Abstract

The issue of low productivity on small farmers’ lands is a matter of concern in many sugarcane producing countries. In Mauritius, some 25 000 small-scale farmers are involved in sugarcane cultivation which is a major source of income for 200 000 rural families. Yield differences as high as 40% exist between the small-scale and large commercial farmers and their causes are often taken for granted. This paper presents part of the findings of a project to better understand, with farmers’ participation, the functioning of the existing small farming systems and their information-seeking behaviours, a study financed by the French government through the Southern African Development Community (SADC). A survey, based on a formal questionnaire, was carried out among 800 farmers in Mauritius. Analysis of the data collected has enabled the prioritisation of factors and constraints affecting productivity, namely, increasing costs of inputs, availability and costs of labour and transport and access to finance and credit facilities. The conditions limiting adoption of good management practices have been identified to be the small-sized farms, low adoption rate of improved technologies and limited contact with advisory and support services. The elaboration of decision support tools to assist these farmers to increase production levels through sustainable and environment friendly production systems will now be generated. There is a need to pursue specific research on cost-cutting farming operations and new production techniques, adopting extension strategies favouring targeted and grouped extension interventions for some categories of small-scale sugarcane farmers. It is believed that the research and extension interventions will ensure the long-term survival of this producer category and will enhance ability to achieve productivity levels that will render the agricultural activities of the small-farmers economically and environmentally sustainable.

Introduction

In the context of world trade globalisation and the reform of the European Union sugar regime, whereby a reduction of 36% in price is imposed on sugar exported to the European Union by countries of the African-Caribbean-Pacific regions including Mauritius, sugar industries in those countries are compelled to adopt various strategies to improve their competitiveness and sustainability.

Strategies in Mauritius are embodied in the 2006–2015 Multi Annual Adaptation Strategic Plan prepared by the Government of Mauritius in partnership with all the stakeholders of the sugar industry (MAAS, 2006).
The Multi-Annual Adaptation Strategy Plan highlighted the absence of economies of scale in the operations of small-farmers. These coupled with poor financial resources at their level have made the small-farmers vulnerable to the decrease in sugar price if urgent measures are not taken to safeguard their interests.

The sugarcane planting community in Mauritius can be classified into three categories as shown in Table 1.

<table>
<thead>
<tr>
<th>Farmer category</th>
<th>Number</th>
<th>Area cultivated (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small-planters (&lt; 10 ha)</td>
<td>23 366</td>
<td>18 850</td>
</tr>
<tr>
<td>Medium- and Large-planters (&gt; 10 ha)</td>
<td>107</td>
<td>3 970</td>
</tr>
<tr>
<td>Corporate (Millers and Non-Millers)</td>
<td>29</td>
<td>43 019</td>
</tr>
<tr>
<td>Total</td>
<td>23 502</td>
<td>65 839</td>
</tr>
</tbody>
</table>

Source: Sugar Insurance Fund Board, 2008

From 2005 to 2007, an average of 4.6 million tonnes canes were harvested, with the small-farmers harvesting around 30.1% of the area under cane, but contributing to only 26.0% of total cane harvested. Average yield was approximately 60.4 tonnes per hectare while the larger producers (large and corporate) averaged 71.1 tonnes per hectare. The yield differential for the period 1996 to 2007 is illustrated in Figure 1.

Scope for enhancing the productivity of the small-farmers in Mauritius therefore exists and, with the financial support of the French government through the Southern African Development Community (SADC), a participatory study was initiated with the objectives of better understanding the functioning of the existing small farming systems and their information-seeking behaviours. It is anticipated that this improved understanding of farmer needs would enable more effective research to be initiated and enhanced advisory services to be dispensed to this category of sugarcane farmers.
Conditions and factors limiting adoption of improved technologies can be addressed through targeted interventions. The elaboration of decision-making models based on farmers’ strategies and factors that restrict their ability to progress are envisaged to enable them to make well-informed decisions. This paper reports the main findings of the study in Mauritius.

Methodology

A comprehensive literature review was undertaken to assess different methodologies used in conducting similar studies in other sugarcane growing countries. No evidence was found of small-scale farmer surveys in the sugarcane growing countries around the world. In fact, there was scant evidence of similar studies in the SADC region.

The following methodology was subsequently developed for the study:

Data collection

A combination of quantitative and qualitative methodologies was used for the study. This paper reports only on the quantitative methodology opted for, namely, a formal survey questionnaire. Using the formal questionnaire and the traditional pen and paper approach, the survey was conducted by twenty enumerators among a stratified random sample of 800 small-farmers selected on four criteria; namely farm size, agro-climatic zones, ownership and rainfed / irrigated conditions.

Questionnaire design and information to be collected

Cognisance was taken of outcomes from previous participatory workshops and working sessions where some preliminary key aspects had been identified. Furthermore, the problem tree technique was used to investigate the possible relationships between low productivity and four major aspects, namely, growers’ practices, land potential and utilisation issues, availability and utilisation of resources, and research, extension and services.

A 15-page questionnaire with six sections was developed to enable data collection on the following:

- Socio-demographic profile (geographic and personal details)
- General information on the sugarcane farming environment
- Resource base (land, sugarcane fields, land ownership, labour, finance, etc.)
- Sugarcane husbandry and use of technology (choice of planting method, land preparation and planting, fertilisation, choice of variety, weed control, etc.)
- Communication facilities and
- Decision making

Data management

A relational database was designed using Microsoft Access software for data entry. A user-friendly GUI (graphical user interface) with the use of drop down menus was developed to provide first level validation for data entry. This facilitated data capture and minimised errors in the keying of data, which was done only for open-ended questions. Data retrieval and analysis were done either directly through query to the database in Access or by using the Statistical Package for Social Sciences (SPSS).

Results

Socio-demographic profile

Nearly 75% of the respondents were male and married, with the great majority (80.1%) being both the head of the family and the farmer. They formed an ageing population, with 47.8% of them between 41 and 60 and 41% above 60 years old (Figure 2).
Among the 70% of the respondents who had at least a full primary education and could be considered as literate, some 30% had a partial secondary education, 10.5% completed the secondary curriculum with only 6% having studied up to tertiary level.

The majority of the farmers (65%) were cultivating sugarcane on a part-time basis, with only 30% doing it as a full-time activity. Very few (5.5%) of the respondents were simultaneously engaged in other farming activities.

Sugarcane farming system

The great majority of the respondents (83%) had a minimum of ten years experience in sugarcane farming. The main reason for being involved in sugarcane farming was mostly because of tradition or on account of a family business they had inherited, with sugar proceeds representing an important source of income.

Regarding succession planning, 54% mentioned that another family member would take over their sugarcane business, while some 41% of the respondents had no opinion on this issue. However, only one respondent replied that he would sell his land.

Parents or family members were the main source of knowledge in sugarcane farming and production for 81.9% of the respondents and 71.7% of these farmers claimed that it was also self-acquired. Formal education and training in sugarcane farming, found to be most useful, was received by only 6.8% of respondents and was provided mainly by the Farmers Service Corporation (FSC) and the Mauritius Sugar Industry Research Institute (MSIRI). Some 20% of the respondents expressed the need for further knowledge or agricultural training in cultural operations and/or sugarcane agronomy in general.

The majority of the respondents were aware of the existence of advisory services, be it FSC, MSIRI or Agricultural Research and Training Unit (AREU), but their perception of the role/function of the extension officer varied from provision of advice only (30% of the respondents), provision of services only (30%), acting as a facilitator for them with other service providers (13%) to provision of training in sugarcane husbandry (6%). It was worth noting that some 22% of the respondents were of the opinion that extension was doing very little or nothing at all. When asked about their expectations of extension, most of the respondents (69%) replied that provision of advice and services should be more available. Acting as a facilitator and conducting training, meetings and seminars should be the major roles of the extension officer and the remaining 31% had no idea or opinion on what extension should be doing for them. A point worth noting is
that some 66% of the respondents did rely on the assistance and support of extension for their farming operations but they stressed that they themselves made the final decision with regards to those operations.

**Sugarcane husbandry practices**

**Date of planting**

An analysis of the responses obtained indicated that short season planting (July to August) was believed to be ideal for over 53% of the respondents in the rainfed regions. For 63% of those in the subhumid (< 1500 mm annual rainfall) to humid (between 1500 to 2500 mm) regions, long to intermediate season planting (from January to May) was favoured (Figure 3).

![Fig. 3—Ideal months of planting by agro-climatic regions.](image)

As for the months that they usually replant, the responses were more or less similar to those mentioned above, suggesting that a slight majority of the farmers usually replant at the appropriate period. A significant number of the respondents stated that they could not replant their fields in the ideal months mainly due to the unavailability of tractors and planting material and to the dry conditions which prevailed at that moment.

**Land preparation and planting**

Apart from some who had recently acquired their cane fields, most of the respondents had replanted their fields at least once since acquisition. About 42% of respondents had done so before the 7th ratoon, about 49% after the 8th to 10th ratoons and the remaining 9% after the 10th ratoon. A majority (91%) had adopted the conventional mechanical land preparation (raking, ploughing and furrowing) while the rest practised minimum tillage or manual land preparation.

**Crop nutrition**

Soil analysis prior to replanting, a service free of charge, was practised by only 25% of the respondents. Of this 25% group, 75% adopted the recommendations for soil amendment and fertilisation which were given to them, based on soil analysis results. For those not doing soil analysis, 80% of them did not use soil amendment and some 75% fertilised their fields on the basis of their past experience or on their neighbour’s practice.

The timing of fertilisation is also a matter of concern. It has been found that more than 80% of the respondents still practised split application of fertilisers either in plant cane or ratoons, a practice which is no longer recommended.
Choice of sugarcane variety

Information on sugarcane varieties, influencing the choice of the variety planted, came from Extension officers for 40% of the respondents, from own/self knowledge for 30% of them and from other farmers for the remaining 22%. The majority of the respondents considered good adaptation and performance as the major criteria for their choice of variety.

Weed control

Chemical weed control, sometimes supplemented with manual weeding, was a common practice among 89% of the respondents. They were aware that weeds directly compete with sugarcane and might be responsible for yield losses. Some 32% of these farmers were not satisfied with their weeding practice due to persisting unfavourable climatic conditions and inappropriate herbicide mixtures for problem weeds.

Major constraints to production.

An important component of the study was to obtain from the respondents what they believed to be the major constraints limiting their sugarcane production, ranking them in order of importance and suggesting appropriate methods on how to minimise the effect of these constraints on productivity. The responses obtained are summarised below.

Increasing cost of inputs

Fertilisers and herbicides are the most commonly used inputs in sugarcane cultivation. The cost of these inputs has been constantly on the increase during the past few years. Figure 4 shows the evolution of nutrient prices for the period 2003 to 2008, where increases of up to 700% were noted.

It was expected that a large majority of the respondents would highlight increasing cost of inputs, mainly fertilisers and herbicides as the most important constraint limiting production. As to how to minimise the effect of this constraint, most of the respondents were of opinion that the authorities, mainly the central government, should intervene through subsidy.

Availability and costs of labour and transport

The availability and cost of labour and transport were reported as being the second most important constraint to sugarcane production (nearly 30% of respondents answered lack of labour,
19% indicating transport and quota problems and 10% mentioned high cost of labour). This has also been observed in past studies, and the labour and transport survey undertaken in 1990 revealed that more than 70% of the small-planters interviewed were facing labour problems, especially during harvesting operations.

Among the solutions proposed by the respondents to counteract these constraints were grouping smaller units into larger blocks to allow for partial or total mechanisation of farming operations and/or recourse to contractors.

**Finance and credit facilities**

The third problem in importance was low profitability resulting from high cost of production coupled with lack of finance and credit facilities. Low profitability as a constraint limiting production is perfectly understandable because if profit is constantly decreasing and if finance and credit facilities are lacking, there will be no further investments, and this will affect productivity. It is important to mention that the authorities have put in place a range of measures in terms of government sponsored loans, subsidies or other soft loans offered by commercial banks to assist sugarcane farmers to stay in business. Lack of information on these measures and difficult access to the facilities offered might in fact be the real cause.

**Discussions and conclusion**

This section highlights the major implications of the above findings for research and extension and eventually the strategies to be developed to meet the needs of the small-scale sugarcane farmers.

**Farmer profile**

The sugarcane farmers in Mauritius are predominantly male. They form an ageing population, with at least a primary schooling tending toward literate part-time farmers. This understanding has some bearing on extension policy and strategy.

A rethinking of extension is necessary to target and to serve a larger farmer population. In particular, specific strategies should be devised to make extension services more accessible to part-time farmers allowing them to benefit from existing new technologies and improved cultural operations.

It is urgent for the extension officers to be more available even if they have to work at odd hours. The judicious use of new communication and IT facilities for effective exchange and dissemination of information is another avenue to be fully explored. It is worth noting that, in this context, the provision of e-services to the small-sugarcane planters in the form of an online system facilitating requests for certain services; for example, a soil analysis service is being offered by the MSIRI in collaboration with the FSC.

**Farming system**

In general, the small sugarcane farmer typically cultivates his own field(s) or fields belonging to the family. Monocropping is a most salient feature of the cropping system and the farmers have a tendency to cultivate only one variety. The fields are usually small in size (0.1 to 2.0 ha) and managed on an individual basis by the farmers themselves. Farmers stated that the final decision regarding their husbandry and production aspects remains theirs.

A vast majority of the respondents have acquired a vast experience in sugarcane farming and they have valid reasons to continue their sugarcane business, justifying why research and extension need to continue developing cost-cutting and innovative strategies to keep this vulnerable group of small-farmers in production.

A good majority of the farmers have not received formal training in sugarcane husbandry and many of them would wish to adopt good management practices to improve their production
levels. This is an area where research and extension may develop tailor-made training programs to meet the aspirations of the small-farmers.

The grouping of small-sized farms into larger units, which is already in progress, apart from enabling the small-farmers to benefit from economies of scale, will also provide a good opportunity for extension, through group techniques, to reach a larger number of farmers through more frequent and regular contacts.

**Husbandry practices**

The major prerequisites for good crop establishment are ideal planting date, elimination of resistant weeds, good land preparation, soil amendment, optimum nutrition, and choice of the most appropriate variety.

If ‘off-the-shelf’ technologies are already in a position to cater for most of these issues, research is still required to continue to develop and seek cost-cutting farming operations or practices and new production techniques that will maintain the competitiveness of small-scale sugarcane farming.

Consequently, where concern by extension is apparent is that nearly 50% of the respondents are not replanting at the appropriate moment, which in most cases would result in a poor crop establishment. The farmers need to be aware of that consequence. Some 75% are not making use of the free soil analysis service available, representing a lost opportunity as farmers could have been practising optimal/sound nutrition.

**Reported constraints**

The increasing costs of inputs, mainly fertilisers, herbicides and labour, coupled with low profitability have been reported to be the major constraints limiting sugarcane production. Research is already adapting new cropping systems which have been successful in other sugarcane producing countries such as Australia for the local sugarcane industry. Through more innovative extension strategies, small-farmers need to be kept informed of these new opportunities and must be encouraged to adopt practices that will enable them to increase their cane yields while at the same time reducing or optimising their production costs.

**Acknowledgements**

The contribution of the French government, which supported the study financially through the Southern African Development Community, is gratefully acknowledged. The authors are also very thankful to the 800 small-scale sugarcane farmers and to all participating institutions for their invaluable collaboration.

**REFERENCES**

ALLÉGEMENT DES CONTRAINTES LIMITANT LA PRODUCTIVITÉ DES PETITS PLANTEURS CANNIERS DE L’ILE MAURICE PAR LA RECHERCHE ET LA VULGARISATION

Par

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MOTS CLES: Petits Planteurs, Productivité Améliorée, Compétitivité, Durabilité.

Resumé

La faible productivité chez les petits exploitants canniers préoccupe beaucoup les pays producteurs de sucre. A Maurice, environ 25 000 petits planteurs cultivent la canne à sucre qui est une source de revenu pour quelques 200 000 familles des régions rurales. Des écarts de rendement atteignant 40% existent entre les gros producteurs et les petits planteurs et les causes sont souvent considérées comme admises. Ce papier présente une partie des conclusions d’un projet initié avec la participation des planteurs pour mieux comprendre le fonctionnement des petits systèmes agricoles et de leurs démarches dans la recherche de l’information agricole. Une enquête, basée sur un questionnaire formel, a été réalisée auprès de 800 petits planteurs à Maurice. Cette étude a été financée par le gouvernement français, à travers la ‘South African Development Community’ (SADC). Une analyse des données recueillies a permis la hiérarchisation des facteurs et des contraintes affectant la productivité, notamment l’augmentation des coûts des intrants, la disponibilité et les coûts de main-d’œuvre, les facilités de transport pendant la récolte et l’accès au financement et au crédit. Les raisons limitant l’adoption des bonnes pratiques de gestion ont été identifiées, à savoir, la petite superficie des exploitations, le faible niveau d’adoption des technologies de pointe et le contact restreint avec les services de vulgarisation et de logistique. Des outils visant à aider les planteurs dans la prise de décisions afin d’accroître leur productivité à travers des systèmes d’exploitations durables et respectueux de l’environnement vont être développés. Une recherche visant à réduire les coûts associés aux opérations culturelles et les nouvelles techniques de production et l’adoption de stratégies vulgarisation favorisant des interventions ciblées pour certains groupes de petits exploitants sont nécessaires. Les interventions de la recherche et de la vulgarisation vont, sans nul doute, assurer la survie de cette catégorie de producteurs dans le long terme, tout en améliorant leur capacité d’atteindre des niveaux de productivité qui vont permettre à leur activité d’être économiquement et écologiquement durable.
INVESTIGACIÓN Y USO DE EXTENSIÓN PARA LA MITIGACIÓN DE LAS RESTRICCIONES QUE LIMITAN LA PRODUCTIVIDAD DE LOS PRODUCTORES DE CAÑA A PEQUEÑA ESCALA EN MAURICIO

Por

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PALABRAS CLAVE: Productores a Pequeña Escala, Mejora de la Productividad, Competitividad, Sostenibilidad.

Resumen

EL PROBLEMA de baja productividad de los pequeños agricultores es un tema preocupante en muchos países productores de azúcar. En Mauricio, unos 25 000 productores a pequeña escala están involucrados en el cultivo de la caña de azúcar como la principal fuente de ingresos para unas 200 000 familias rurales. Diferencias en la productividad de hasta el 40% existen entre los productores de pequeña escala y los grandes productores comerciales y las causas muchas veces se toman como algo normal. Este trabajo presenta algunos de los resultados de un proyecto encaminado a entender mejor la forma en que funcionan los pequeños sistemas agrícolas y sus comportamientos de búsqueda de la información, un estudio realizado con la participación de los pequeños productores y financiado por el gobierno francés a través de la Comunidad de Desarrollo Sudafricana (SADC, en inglés). Una encuesta, basada en un cuestionario formal, se realizó entre 800 productores de caña de Mauricio. El análisis de los datos ha permitido la priorización de los factores y limitantes que afectan la productividad, incrementando los costos de producción, la disponibilidad y costos de la mano de obra y transporte y el acceso a financiamiento y crédito. Se identifican las condiciones que limitan la adopción de prácticas adecuadas de manejo tales como el tamaño pequeño de las fincas, el bajo índice de adopción de tecnologías mejoradas y el poco contacto con servicios de asesoría y apoyo. La elaboración de herramientas para la toma de decisiones para ayudar a estos productores a mejorar sus niveles de producción a través de sistemas de producción sostenibles y amigables con el ambiente serán generadas. Existe una necesidad de realizar investigación específica sobre las operaciones que permitan reducir costos en el cultivo y nuevas técnicas de producción, la adopción de estrategias de extensión que favorecerán grupos específicos y tendrán intervenciones conjuntas para algunas categorías de productores de caña a pequeña escala. Se cree que las intervenciones de investigación y extensión asegurarán la sobrevivencia a largo plazo de esta categoría de productores y mejorará la habilidad para alcanzar niveles de productividad que resultarán en sostenibilidad de las actividades agrícolas de los pequeños productores, las cuales serán amigables con el ambiente.
EXTENSION AND ADOPTION OF THE ‘SIX EASY STEPS’ NUTRIENT MANAGEMENT PROGRAM IN SUGARCANE PRODUCTION IN NORTH QUEENSLAND

By

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KEYWORDS: Nutrient Management, SIX EASY STEPS, Reef.

Abstract

In tropical north Queensland, the need for accelerated adoption of best-practice nutrient management has become more urgent because of increasing pressures for profitable cane production to be achieved in combination with environmental awareness. The latter of these contributory factors is driven primarily by the proximity of sugarcane-producing areas to the World Heritage-listed Great Barrier Reef. The SIX EASY STEPS program was developed to enable easy adoption of best-practice nutrient management principles on-farm and to promote sustainable nutrient use in the Australian sugar industry. This system, aimed at sustainable sugarcane production, encourages growers to use knowledge of soils, nutrients and the sugarcane crop to make informed decisions about their fertiliser inputs. Although growers usually have an inherent understanding of these concepts, a short-course program is being used to promote the development and use of appropriate nutrient management plans for targeting nutrient inputs. This paper reports on an assessment of this educational process which is linked to specific follow-up and grower-interactive activities. In general, it has been found that growers and their advisers value the opportunity to attend the short-course program. However, development of individual nutrient management plans will probably not be progressed by growers without further input from extension officers. The use of participative on-farm strip trials that compare usual grower nutrient management practices to those promoted by the SIX EASY STEPS, is a useful and practical means of demonstrating the worth of best-practice nutrient management to growers.

Introduction

During the past 15 years, Australian sugar industry scientists have been modifying nutrient management guidelines for sugarcane production. Led by BSES Limited, the Australian sugar industry’s principal research, development and extension (RD&E) organisation, the changes have included refined nutrient application rates and tighter recommendations on timing and placement of nutrient applications.

The impetus for revamping nutrient management recommendations arose from the increasingly narrow profit margins of sugarcane production and rising environmental awareness by the industry. No longer could nutrient advice concentrate only on sugarcane yields but would also have a very strong focus on sustainability which includes aims at profitable cane production in combination with minimal impact on the agricultural and wider environments.

The new sustainability guidelines, therefore, encompass optimising sugarcane production and profitability while minimising nutrient losses due to volatilisation, denitrification, leaching and soil erosion.
The new sustainability guidelines have been encompassed in the SIX EASY STEPS strategy (Schroeder et al., 2010) which is being rolled out to Australian sugarcane growers under a one-day short-course extension program called ‘Accelerating the adoption of best-practice nutrient management’. The course provides canegrowers with the information and tools on how to develop sustainable nutrient management plans for each block on their farms.

This paper provides an historical summary of nutrient use within the Australian sugar industry and describes the concept of sustainable nutrient management in the context of environmental and government pressures to limit nutrients into the Great Barrier Reef Lagoon.

It also provides a summary of the development, operation, attendance and impact of the SIX EASY STEPS program.

**History of nutrient use**

Early BSES Limited sugarcane technologists recognised the need to devise balanced nutrition strategies (Maxwell, 1901). The BSES Limited fertiliser advisory service to growers commenced in about 1940. An upsurge in sugarcane nutrition research began in the 1970s (Schroeder et al., 1998) resulting in a set of broad, generalised recommendations across regions and soil types (Calcino 1994, Wood et al., 1997, Calcino et al., 2000).

While useful, the recommendations afforded little recognition of differences in soil type, and in particular the nitrogen (N) mineralisation potential of soils. The need to refine nutrient recommendations to minimise adverse environmental impacts while maintaining profitability and soil fertility was recognised in the late 1990s.

The resulting SIX EASY STEPS nutrient recommendations are now standards accepted by industry and government.

In the past, canegrowers have generally over-fertilised especially with N. Schroeder et al. (2002) showed that on average across the industry:

- 80% of growers surveyed applied rates of N fertiliser on fallow plant cane in excess of BSES Limited recommendations. The majority of these applied more than 50 kg N/ha above the recommended rates.
- 45% applied rates of N on replant cane (cane planted soon after the destruction of the previous crop without an intervening fallow) in excess of recommendations.
- 44% applied rates of N on ratoon cane in excess of recommendations.

These percentages did not vary much between mill areas, with the exception of Innisfail and Babinda. Most growers in these areas applied recommended rates or lower.

Risk aversion has been a major factor motivating growers to apply nutrients, especially N, above recommended rates (Thorburn et al., 2003). Extra N was seen as economical insurance to protect profits against unforeseen environmental impacts during the 12- to 14-month growing period.

This type of approach was not sustainable, as N and phosphorus (P) are the two agricultural nutrients that have the potential to adversely impact on water quality and, ultimately, coral reefs.

However, data supplied by Incitec Pivot Limited (the major manufacturer and supplier of fertilisers to the Australian sugar industry), indicate that N and P application rates have shown a downward trend over the last decade (Tables 1 and 2).

The company compiles annual estimates of nitrogen and phosphorus use in Australia’s main sugarcane districts. While imperfect, these figures provide possibly the most reliable picture of temporal and spatial fertiliser usage by Australian canegrowers.

Since 1996, the average nitrogen application rate across the Australian industry has fallen by 20% (Table 1). During the same period, the average phosphorus application rate across the Australian industry has fallen by 30% (Table 2).
Table 1—Nitrogen application rates (kg N/ha) across Australian sugarcane growing regions 1996–2007.

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Source: Garry Kuhn, Product Stewardship Manager, Incitec Pivot.

Table 2—Phosphorus application rates (kg P/ha) across Australian sugarcane growing regions 1996–2007.

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Source: Garry Kuhn, Product Stewardship Manager, Incitec Pivot.

The accuracy of the data is supported by regional surveys by BSES Limited such as the Wet Tropics Tully/Murray River catchment application figures (Mahon and Hurney, 2008). That survey found that growers are currently applying, on average, 141 kg N/ha, 22 kg P/ha and 107 kg K/ha. These rates are consistent with current BSES Limited recommendations based on the SIX EASY STEPS program (Schroeder et al., 2009). The survey also revealed that nutrient application methods take into consideration potential losses from the soil that include leaching, run-off and gaseous losses (such as volatilisation and denitrification). The majority of the survey respondents were also aware of, and actively implementing, sustainable farm-management practices on-farm.

Unfortunately, in some catchments and on some individual farms throughout the industry, the average N and P application rates are still above industry recommendations. Additionally, in some locations, the timing and placement of nutrient applications needs to be improved to reduce adverse off-site impacts. The nutrient management practices outlined in the SIX EASY STEPS program are regarded by authorities and industry as the best way to achieve these targets. (Anon., 2009)

Sustainable nutrient use, the environment and government

As indicated above, BSES Limited and its partners (CSR Sugar and the previous Queensland Department of Natural Resources and Water (NRW)) working within projects funded by the Sugar Research and Development Corporation (SRDC) and the Cooperative Research Centre for Sustainable Sugar Production (Kingston and Lawn, 2003) undertook research aimed at enhancing the sustainability of the Australian sugar industry well before two recent key government initiatives. In January 2009, the Australian Government commenced its $200 million Reef Rescue Plan, and in mid-2009 the Queensland State Government introduced legislation to control the use of nutrients in sugarcane production in areas adjacent to the Great Barrier Reef ecosystems. Although applied in different ways, both initiatives are designed primarily to improve the quality of water draining into the Great Barrier Reef lagoon.
The Great Barrier Reef was officially listed as a World Heritage Site in 1981 as an example of superlative natural phenomena. The Great Barrier Reef World Heritage Area is the world’s largest coral reef ecosystem and one of the most complex natural systems on earth. The Reef extends 2000 km along the Queensland coast, comprises 2900 individual reefs including 760 fringing reefs (Johnson and Marshall, 2007), and covers an area of 35 million hectares. It directly contributes over $5.8 billion annually to the gross domestic product of the Australian economy and supports approximately 63000 jobs (Jones, 2009; Rudd et al., 2007; Anon, 2005). Many coastal communities which evolved as the sugar industry developed in the late 19th century colonisation of Queensland rely heavily on the sugar industry and Great Barrier Reef tourism for their future.

Sugarcane cropping has been identified as posing a high risk of nutrient transport in Reef catchments primarily due to the area under production (Furnas, 2003) and the location of the industry adjacent to the Reef. CSIRO, Great Barrier Reef Marine Park Authority and James Cook University have conducted modelling which has identified run-off hot spots and determines the temporal and spatial aspects of the delivery of pollution to the Reef. These include areas of high fertiliser use (Maughan et al., 2007) particularly in the Wet Tropics region of north Queensland.

Along the Queensland coast, 31 river catchments drain into the Great Barrier Reef. Sugarcane is grown in approximately half the catchments comprising seven in the Wet Tropics (Mossman to Tully), one in the Herbert (Ingham), three in the Burdekin (Ayr), four in central Queensland (Proserpine to Sarina) and one in south Queensland. Very little cane production occurs in the south Queensland catchment.

In October 2007, 14 months before being elected to government, the Federal Australian Labor Party issued a policy document titled ‘Labor’s Reef Rescue Plan’ whose aim was to ‘tackle climate change and improve water quality in the Reef through a range of activities’ (Rudd et al., 2007). The policy document stated there was a growing body of scientific evidence linking the declining health of the Great Barrier Reef to poor water quality. Following Labor’s election, the five-year Reef Rescue Plan was implemented on 1 January 2009 to improve farming practices in the Great Barrier Reef catchment. Included in those practices was improved nutrient management on sugarcane farms.

At the Queensland state government level, the Great Barrier Reef Protection Bill which took effect from 1 January 2010 aims to reduce the levels of farm fertiliser, pesticide and sediment harming the Reef (Jones 2009).

Given the pressure and incentives from State and Commonwealth governments and the sugar industry’s desire and commitment to reduce its environmental footprint, the SIX EASY STEPS nutrient management program is having a major role in improving the industry’s sustainability while satisfying the community’s expectations of the industry.

**Development of the SIX EASY STEPS workshops**

The SIX EASY STEPS workshop program (Schroeder et al., 2010) was developed as a district-specific, interactive, practical and interesting short course specifically for canegrowers (Schroeder et al., 2006a). This integrated nutrient management tool incorporates the recent refinements to nutrient recommendations for the Australian industry and has been strongly supported by the industry.

The program consists of the following six components:

1. Knowing and understanding your soils
2. Understanding and managing nutrient process and losses
3. Regular soil testing
4. Adopting soil-specific nutrient management guidelines
5. Checking on the adequacy of nutrient inputs (e.g. leaf analyses)
6. Keeping good records to modify nutrient inputs when and where necessary
The program provides:

- guidelines for the implementation of balanced sugarcane nutrition to optimise productivity and profitability without adversely affecting soil fertility or the environment i.e. sustainable sugarcane production
- skills for growers to develop their farm nutrient management plans

A key message of the workshops is that soil test analyses are crucial to providing the necessary information on which to develop the most appropriate nutrient management strategy for individual farms.

The new nutrient recommendations focus on regional environments and soil characteristics. Management guidelines are soil specific by recognising soil attributes such as colour, texture, chemical properties and position in the landscape.

The SIX EASY STEPS program also promotes the development and implementation of fertiliser strategies for a full crop cycle. The ‘whole of crop cycle’ fertiliser recommendation approach is compatible with a more strategic, longer-term attitude to nutrient management promoted by industry research, development and extension organisations.

Before rolling out the SIX EASY STEPS program to the industry, BSES Limited sought input from extension staff and growers. The final product incorporated suggestions to enhance the program and improve its effectiveness to grower stakeholders.

With the extension of the SIX EASY STEPS nutrient management program, Australian canegrowers are now in a far better position to better understand their soils, their nutritional requirements and techniques to avoid adverse off-site impacts.

**Operation of SIX EASY STEPS workshops**

A SIX EASY STEPS workshop lasts for approximately six hours. Attendance numbers are restricted to maximise interaction between the workshop presenters and the usual nine to 15 attendees. Each participant receives a workshop manual to keep for future reference. The manual provides detailed information on all the material covered during the workshop including a laminated, one-page nutrient recommendation sheet which lists advised inputs based on soil analyses.

The cornerstone of the workshop is a computer-based presentation that comprehensively covers all aspects of the SIX EASY STEPS approach to nutrient best management practice. The workshop is designed to be as interactive as possible. Attendees are strongly encouraged to ask questions and offer observations relating to their own experiences for discussion by the group. Working in small sub-groups with the assistance of the presenters, participants work through several exercises to reinforce information presented earlier in the workshop. Participants are given a certificate of attendance upon completion of the workshop. The certificate is regarded favourably when the grower applies for funding to adopt strategies to reduce off-site environmental impacts.

The first SIX EASY STEPS workshop was held in south Queensland in 2005. With the introduction of the Commonwealth Government’s Reef Rescue Program on 1 January 2009, the roll-out of the workshops across all catchments adjacent to the Great Barrier Reef became a priority for BSES Limited extension officers and scientists.

Funding to conduct the workshops is being provided by the Australian Government under the Reef Rescue Plan. Operating in conjunction with these workshops, partial funding is also being provided by the government to enable growers to implement on-farm activities that will lead to improved water quality on the Great Barrier Reef by reducing the run-off of nutrients, pesticides and sediments from agricultural land. (Rudd et al., 2007).

**Attendance and impact of the SIX EASY STEPS workshops**

A total of 3842 growers from north to central Queensland produce sugarcane in the catchments that drain into the Great Barrier Reef (CANEGROWERS Brisbane, pers. comm. 2009).
The South Queensland contribution to Reef run-off is very small and is not included in the following discussion.

To 30 June 2009, approximately 630 growers had voluntarily attended a SIX EASY STEPS workshop. This 16% of the total grower number is estimated to represent approximately 30% of the area producing cane. In addition, about 100 extension staff, natural resource management representatives, sugar industry productivity officers and agribusiness advisers also attended workshops.

SIX EASY STEPS workshops were rolled out across north Queensland in February 2008, one to two years later than in the rest of the industry. Detailed records of attendance at north Queensland workshops show that 40625 ha or 31% of the area under sugarcane cropping has been represented at SIX EASY STEPS workshops (Table 3).

Table 3—Details of attendance at SIX EASY STEPS workshops in north Queensland (Wet Tropics and Herbert).

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<tr>
<th>Region</th>
<th>Catchments in region</th>
<th>Number of grower attendees</th>
<th>Number of other attendees</th>
<th>Number of workshops</th>
<th>Proportion of area under cane represented (%)</th>
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<tr>
<td>Mossman</td>
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<tr>
<td>Mulgrave</td>
<td>Barron Russell-Mulgrave</td>
<td>59</td>
<td>8</td>
<td>5</td>
<td>62.4</td>
</tr>
<tr>
<td>Babinda-Innisfail</td>
<td>Russell-Mulgrave Johnstone</td>
<td>88</td>
<td>18</td>
<td>8</td>
<td>52.4</td>
</tr>
<tr>
<td>Tully</td>
<td>Tully Murray</td>
<td>37</td>
<td>11</td>
<td>5</td>
<td>28.5</td>
</tr>
<tr>
<td>Herbert</td>
<td>Herbert</td>
<td>25</td>
<td>4</td>
<td>2^</td>
<td>11.3</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>243</td>
<td>42</td>
<td>23</td>
<td>31.3</td>
</tr>
</tbody>
</table>

* Mitchell catchment does not run to Great Barrier Reef lagoon
^ Several earlier workshops not included

To assess the immediate impact of the workshops on grower attitudes, a short survey was conducted at the conclusion of the last 14 workshops. The results confirmed a very strong positive opinion of the value of this extension activity among participants across all six regions (Table 4).

Table 4—Results of 14 SIX EASY STEPS workshop attitudinal surveys conducted across all regions in north Queensland.

<table>
<thead>
<tr>
<th>Question</th>
<th>Number of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Was the course useful?</td>
<td>175  2  0</td>
</tr>
<tr>
<td>Would you recommend the course to other growers?</td>
<td>175  1  0</td>
</tr>
<tr>
<td>Was the course too difficult to understand?</td>
<td>3  32  130</td>
</tr>
<tr>
<td>Is there anything you would like changed or dropped from the course?</td>
<td>10  160</td>
</tr>
</tbody>
</table>

When participants at the last ten workshops were asked to provide an overall assessment of the workshop, the average score of the 119 respondents was 9.1 out of 10. Forty per cent of respondents rated the workshop at the maximum score of 10.

In 2009, a survey of 88 cane growers in all regions across Queensland who had completed a SIX EASY STEPS workshop was conducted (RWUEI 2009, T Anderson pers. comm.). The survey
assessed on-farm practical changes that had been implemented as a result of attendance at a workshop. The survey results confirmed that the initial positive impact of the workshops translated into the adoption of sustainable practices. Some of the survey results include:

- Ninety-five per cent of growers had taken a soil test in the previous two years to determine the most appropriate nutrient management program for a particular cane field or area of the farm.
- Sixty-one per cent changed the type of fertiliser they used to a more economical or nutritionally appropriate product.
- Fifty-eight per cent reduced fertiliser rates. The confidence they gained from the course to reduce fertiliser rates without fear of loss of productivity was stated as a significant factor in the decision to reduce nutrient inputs.
- Almost all growers who grew an alternative crop reduced fertiliser inputs in the following plant cane crop.

The reasons for the success of the workshops are believed to be due to several factors. Canegrowers are increasingly aware of the environmental issues due to over-fertilising and inappropriate timing and placement of fertiliser applications. The sugar industry understands that government and community pressure on the industry, whether warranted or not, has to be addressed through appropriate nutrient management strategies. The workshops were developed in close cooperation with growers and extension staff to produce a product that is relevant, interactive, interesting and useful. Active participation in the workshops is seen as the key to their success.

**Training program support**

The SIX EASY STEPS training program is supported by a range of initiatives that are currently under way or planned (Schroeder et al., 2010). These include:

- a workshop reference manual
- regional soil reference booklets (Wood et al., 2003, Schroeder et al., 2006b, Schroeder et al., 2007a, Schroeder et al., 2007b) which include soil-specific nutrient management guidelines for cane production in each district
- nutrient management plans which will include farm maps with soil overlays
- replicated on-farm strip trials (Salter et al., 2008) to compare SIX EASY STEPS nutrient recommendations with growers’ own current fertiliser strategies
- the NutriCalc calculator to determine nutrient requirements based on soil test results
- two new decision support tools for minimising off-site movement of nutrients (Moody et al., 2008): ‘Soils Constraint and Management Package’ (SCAMP) that utilises soil analytical data to identify soil constraints to long-term sustainability and ‘SafeGauge for Nutrients’.
- trials to determine the nutrient requirements of new farming systems (Wood et al., 2008)

**Conclusion**

The development and delivery of the SIX EASY STEPS program and implementation of the program’s nutrient recommendations and management practices have been significant achievements for the Australian sugar industry. The program is successfully addressing industry, community and government targets relating to sustainable nutrient use in the sugarcane production system.

**Acknowledgements**

The SIX EASY STEPS program forms part of the nutrient management initiative involving BSES Limited, CSR Ltd and the Queensland Department of the Environment and Resource Management (DERM). It is supported by CANEGROWERS and receives funding from the Sugar Research and Development Corporation (SRDC), Queensland Primary Industries & Fisheries
(QPIF) and the Australian Department of the Environment, Water, Heritage and the Arts (DEWHA). Under the Reef Rescue Program, the Australian Government provided partial funding through Terrain Natural Resource Management to assist with the delivery of some of the SIX EASY STEPS workshops.

REFERENCES


VULGARISATION ET ADOPTION DES ‘SIX ETAPES FACILES’ POUR LE PROGRAMME DE GESTION DES ENGRAIS DANS LA PRODUCTION DE LA CANNE DANS LE NORD DU QUEENSLAND

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MOTS-CLES: Gestion des Engrais, SIX ETAPES FACILES, Récif.

Résumé

DANS LE NORD du Queensland tropical, la nécessité d’adopter une meilleure pratique pour accélérer la gestion des engrais est encore plus urgente en raison des pressions exercées pour atteindre une production de canne rentable tout en prenant compte de l’environnement. Ce dernier facteur dépend principalement de la proximité des planteurs de cannes avec la Grande Barrière de Corail reconnue par le Patrimoine Mondial. Le programme de SIX ETAPES FACILES a été développé pour permettre l’adoption de meilleures pratiques de gestion en éléments nutritifs sur les fermes et pour
promouvoir l’utilisation durable d’engrais dans l’industrie sucrière australienne. Ce système vise à une production durable de la canne, encourage les planteurs à mieux connaître les sols, les éléments nutritifs et la culture de la canne afin de prendre des décisions en toute connaissance de cause sur leurs apports d’engrais. Bien que les producteurs ont généralement une connaissance inhérente de ces principes, un cours de courte durée est proposé pour promouvoir le développement et l’utilisation des plans de gestion appropriés des éléments nutritifs afin de cibler les apports d’engrais. Cette présentation rapporte l’évaluation de cette méthode d’éducation qui est liée à des activités spécifiques et encourage des interactions entre les planteurs. En général, il a été constaté que les planteurs et leurs conseillers ont apprécié la possibilité de suivre ce cours de courte durée. Toutefois, la gestion individuelle ne va probablement pas progresser sans une aide supplémentaire des officiers de vulgarisation. La mise en place d’essais par bande sur les fermes avec la participation des planteurs qui comparent les pratiques de gestion des éléments nutritifs habituels à celles qui sont préconisées par les SIX ETAPES FACILES, est un moyen utile et pratique de démontrer une meilleure gestion des engrais aux planteurs.

EXTENSIÓN Y ADOPCIÓN DEL PROGRAMA DE MANEJO DE NUTRIENTES ‘SIX EASY STEPS’ (SEIS PASOS FÁCILES) EN LA PRODUCCIÓN DE CAÑA DE AZÚCAR EN EL NORTE DE QUEENSLAND

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PALABRAS CLAVE: Manejo de Nutrientes, SIX EASY STEPS, Arrecife.

Resumen

EN EL NORTE tropical de Queensland, se ha hecho urgente la necesidad de adoptar rápidamente las mejores prácticas para el manejo de nutrientes debido a las presiones crecientes en cuanto a la producción rentable de caña de azúcar en combinación con el cuidado del ambiente. El último de estos factores se debe a la proximidad de las áreas de producción de caña con la Gran Barrera del Arrecife que ha sido declarada Patrimonio Mundial. El programa de los ‘Seis Pasos Fáciles’, Six Easy Steps, en inglés, se desarrolló para permitir la fácil adopción de los principios de las mejores prácticas de manejo de nutrientes en el campo y para promover el uso sostenible de los nutrientes en la agroindustria azucarera australiana. Este sistema, orientado a la producción sostenible de caña, insta a los productores a usar el conocimiento de los suelos, nutrientes y el cultivo de caña para tomar decisiones documentadas sobre el uso de sus fertilizantes. Aunque los productores de caña generalmente tienen un conocimiento básico de estos conceptos, se está utilizando un curso corto para promover el desarrollo y uso apropiado de planes de manejo de nutrientes. Este trabajo reporta un estudio que se hizo de este proceso educativo que tiene un seguimiento específico y actividades interactivas para los productores de caña. En general, se ha encontrado que los productores y sus asesores valoran la oportunidad de atender este programa. Sin embargo, el desarrollo de los programas individuales de manejo de nutrientes no progresará sin el apoyo de los oficiales extensionistas. El uso de ensayos de franjas demostrativas donde se compara la práctica usual del productor y las prácticas promovidas por el programa Six Easy Steps, es un medio práctico y útil para demostrar el valor de un programa de mejor manejo de nutrientes a los productores.
LIVER:BODY MASS$^1$ RATIOS OF LAB RATS DRINKING WATER WITH CALORIC AND HYPO-CALORIC SWEETENERS ADDED


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KEYWORDS: Sucrose, Fructose, Aspartame, Sucralose, Liver Tissue.

Abstract

CARBOHYDRATES are metabolised in the livers of mammals. In order to determine the effect of consumption of sweeteners on the liver, mass ratios of the mass of the liver to total body mass were assessed in experiments carried out in laboratory animals. Weaned male Wistar rats were fed daily with a solid diet ad libitum (Global Teklad), and given water with: 1) Fructose, 15%; 2) Sucrose, 10%; 3) Aspartame, 0.3%; 4) Sucralose, 0.19%, and 5) Control, unsweetened water. After 73 days, the animals were sacrificed, and hepatic tissues were removed. Daily water volume consumption, amount of ingested food, and body mass gain were assessed. Results were statistically compared (p<0.05), showing that fructose in water promoted the highest mass gain in the rats. Rats that consumed sucrose had the lowest food consumption and the lowest final mass gain, statistically similar to those of the control lot. Study animals that had water with hypo-caloric artificial sweeteners, aspartame and sucralose, ingested the same amount of food as the control counterparts but were fatter than control and sucrose lots, but lower than the fructose-drinking specimens. The fructose-consuming lot showed a tendency to greater liver mass:body mass ratio even though it did not have statistically-significant values with respect to the other lots evaluated. A contrary tendency of liver:body mass ratios, smaller than the other three lots, was produced in the lots ingesting the two hypo-caloric sweeteners, although they did not reach statistically-significant values. These results should be further studied in a longer term experiment (250–300 days).

Introduction

The prevalence of obesity is increasing around the world, and is a significant public health problem in many countries. Consumers are increasingly concerned about the quality and safety of

$^1$ In the sciences, mass and weight are different properties. Mass is a measure of the amount of matter in the body while weight is a measure of the force on the object caused by a gravitational field. For example, a person with 60 kg mass, weighs 60 kg-force in Earth’s surface; but, the same person, in the Moon surface would only weigh around 10 kg-force; however, his/her mass will be 60 kg. In common language, the term ‘weight’ is wrongly used as a synonym of ‘mass’. The mass unit in the IS is the kilogram, kg
many products present in the diets of industrialised countries, in particular, the use of artificial sweeteners and dietary supplements.

General apprehension also exists regarding the possible long-term health effects. Of particular concern are the potential carcinogenic effects of these products (Vermunt et al., 2003; Soffritti et al., 2006). Fructose is a monosaccharide found in fruits and honey that in recent decades has been enzymatically obtained from starch hydrolysis, mainly from maize (Bray et al., 2004). Some authors have suggested that the ingestion of fructose syrups may be responsible for much of the obesity problem seen in today’s world (Aeberli et al., 2007; Gaby, 2005; Johnson et al., 2007).

Fructose is directly transported to the liver without increasing insulin in blood plasma, mobilising fats, and at a higher rate than glucose, which is controlled by phosphofructokinase (Voet and Voet, 1992). The liver, kidneys, and small intestine are the main metabolic utilisation sites for sugar (Murray et al., 1994). Aspartame and sucralose, some of the most commonly-added artificial sweeteners to foods and drinks, have also been studied, but still no conclusive data are available (Jürgens et al., 2005, Teff et al., 2004).

To corroborate the effects that these sweeteners have in liver when chronically consumed, especially in infancy and adolescence, these sweeteners were added daily to the drinking water of male Wistar rats after they were weaned, using them as models, until they reached ‘adulthood’. Both food and water were given *ad libitum*.

**Materials and methods**

The investigation protocol was approved by the Institutional Program for the Care and Use of Animals from the Animal Experimentation Unit, Complex E, Faculty of Chemistry, UNAM (*Universidad Nacional Autónoma de México*, National Autonomous University of Mexico in Spanish). Male Wistar rats were used with an average initial body mass of 39.2± 0.4 g.

Rats were placed in individual boxes and acclimated for seven days in a controlled environment at a temperature of 23±1°C and a 12 hour cycle of light/dark and fed with the same solid diet *ad libitum* (Global Teklad) and tap drinking water. At the end of the inuring week, they were randomly distributed in five groups of 9 rats each one. Four groups had different sweeteners in their drinking water.

Two treatments were with natural sugars comparable to those found in soft drinks:

1) Fructose solution, 15% (Jürgens et al., 2005), and
2) Sucrose solution, 10% (González, 2006).

Two other treatments utilised hypocaloric sweeteners:

3) Aspartame solution, 0.3% (González, 2006), and
4) Sucralose solution, 0.19% (González, 2006).

Finally, the fifth group received

5) Unsweetened drinking water (control).

Sweeteners were dissolved in drinking water. After daily intake was measured, residual water was discarded and freshly-prepared solutions were placed after water troughs were perfectly washed in order to avoid bacterial contamination. Body mass gain was individually measured for each of the nine rats of the five groups by means of an analytical weighing scale (OHAUS model Scout II), three times per week; the average was calculated by group/day. In the same way, food and liquid were measured daily for each rat.

After 73 days of feeding, the animals were sacrificed and their livers removed for histological analysis (Genneser, 1989; Ross et al., 1992). Experimental data obtained were statistically processed with analysis of variance (ANOVA, p≤0.05), between: a) Body mass gained by specimens and lots for the duration of the experiment, and b) Differences in the mass ratios of the amounts of food ingested by specimens and lots for the duration of the experiment. Once it was

corroborated that statistically-significant differences existed, a comparison between groups, using a student's $t$-distribution ($p \leq 0.05$), was performed (Pedrero and Pangborn, 1996).

**Results and discussion**

Figure 1 presents the average values of liver mass with respect to total mass gain from the nine rats of each group. A tendency towards higher liver:body mass ratios was observed in the animals that ingested fructose. Even though these data were not statistically different ($p<0.05$), this finding will have to be studied in a longer term experiment (250–300 days) to establish its possible meaning.

Results obtained in this research show that drinking fructose water solutions promoted the highest mass gain in Wistar rats in comparison to other caloric and hypo-caloric sweeteners (Figure 2). Statistical differences were found among the rat group that ingested water containing caloric sweeteners (fructose, with respect to sugar and control), with the highest mass gain for the fructose-consuming group and the lowest for the sugar-consuming group.

There were no statistically-significant differences in mass gain between the sugar-consuming and control lots ($p<0.05$). When a comparison was made between both groups consuming hypo-caloric sweeteners, there were no significant differences. However, they were statistically different with respect to the other three groups (sucrose, fructose, and control).

The highest body mass gain from these two groups consuming hypo-caloric sweeteners was observed in the aspartame-consuming group. Once the rats reached adulthood, daily water consumption was up to 110 mL for the sugar group whereas for the control and aspartame-consuming groups, it was only 30 mL, with the fructose-consuming group ca. 90 mL, and the sucralse-consuming group around 55 mL (Figure 3).

Daily food intake was on average 19 g for the groups consuming hypo-caloric sweeteners and controls, and 12 g for the groups consuming caloric sweeteners (Figure 4). As had been expected, a preference was observed on the part of the animals for the liquid containing caloric sweeteners, along with a reduction of the ingestion of solids, where the daily caloric ingestion was concerned. Histological analysis showed that the hepatic tissue of the rats that drank fructose solution showed a greater accumulation and concentration of extracellular lipids.
It is interesting to observe that in spite of the similar daily consumption of water, and food with similar caloric intake (Martínez-Tinajero et al., 2009), the animals that consumed hypo-caloric sweeteners are statistically fatter than those of the control group. A recent paper suggests that metabolic alterations might indeed be occurring after ingestion of these artificial sweeteners (Dyer et al., 2007).

On the other hand, the groups ingesting hypo-caloric sweeteners showed a tendency to lower liver:body mass ratio, even though this did not reach statistically-significant values. (Figure 1). Rats that consumed hypo-caloric sweeteners had similar solid food intakes to that of the control group.

Nevertheless, when the liquid intake was analysed, it was observed that the animals receiving the hypo-caloric sweeteners showed a statistical difference where the sucralose-consuming lot was concerned (p<0.05). This behaviour should also be evaluated in a longer term experiment (250–300 days) to establish its possible meaning.

**Conclusions**

Caloric sweeteners promote water intake. However, fructose promotes a higher mass gain than sugar. Moreover, ingestion of fructose brings about an accumulation of extracellular lipids in liver tissue, as well as a slightly higher liver:body mass ratio when it is compared to sugar-ingesting and control groups.

Although hypo-caloric sweeteners did not contribute to caloric intake, they promoted greater mass gain than sugar-ingesting and control groups. Additionally, a slight tendency to a lower liver:body mass ratio was found among the sucralose- and aspartame-ingesting group when compared to the sugar-ingesting and control groups. These effects on liver:body mass ratios for both natural and hypo-caloric sweeteners should be studied further.

**Acknowledgements**

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RAPPORT FOIE : POIDS CORPOREL DE RATS DE LABORATOIRE CONSOMMANT DE L’EAU CONTENANT DES EDULCORANTS CALORIQUES ET HYPO-CALORIQUES

Par

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Mots Clés : Saccharose, Fructose, Aspartame, Sucralose, Tissus Hépatiques.

Résumé

LES CARBOHYDRATES sont métabolisés dans le foie des mammifères. Afin de déterminer l'effet de la consommation d'édulcorants sur le foie, les rapports de la masse du foie et la masse du corps total ont été évalués lors des expériences menées sur des animaux de laboratoire. Des rats adultes mâles Wistar ont été nourris quotidiennement avec une alimentation solide ad libitum et de l'eau contenant (1) 15% de fructose, (2) 10% de saccharose, (3) 0.3% d'aspartame, (4) 0.19% de sucralose, et (5) de l'eau non sucré, comme contrôle. Après 73 jours, les animaux ont été sacrifiés et les tissus hépatiques retirés. La consommation journalière du volume d'eau, la quantité des aliments ingérés et le gain de poids corporel ont été évalués. Les résultats ont été comparés statistiquement (p<0.05), montrant que le fructose dans l'eau favorise le gain de poids le plus élevé chez les rats. Les rats consommant du saccharose avaient la plus faible consommation alimentaire et le gain de poids le plus bas, statistiquement similaire au contrôle. L’étude des animaux qui avaient bu de l'eau avec les édulcorants hypo caloriques artificiels, l'aspartame et le sucralose, ont consommé la même quantité de nourriture que ceux du contrôle mais étaient plus gros que les lots de contrôle et de saccharose, et inférieur à ceux qui avaient consommé du fructose. Ces derniers ont montré une tendance à un plus grand rapport entre la masse du foie et du corps, même si les différences n’étaient pas statistiquement significatives. Une tendance contraire au ratio foie:poids corporel, plus faible que les trois autres lots, a été noté dans les lots avec les deux édulcorants hypo-caloriques, bien qu’ils n'ont pas atteint des valeurs statistiquement significatives. Ces résultats devraient être étudiés plus profondément dans une expérience à long terme (250–300 jours).
INDICES TEJIDO HEPÁTICO:MASA CORPORAL EN RATAS DE LABORATORIO QUE BEBIERON AGUA ENDULZADA CON EDULCORANTES CALÓRICOS E HIPO CALORICOS

Por


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Palabras Clave: Sacarosa, Fructosa, Aspartame, Sucralosa, Tejido Hepático.

Resumen

LOS CARBOHIDRATOS son metabolizados en el hígado de los mamíferos. Con el propósito de determinar el efecto que tiene en el hígado el consumo de edulcorantes, se llevó un a cabo un estudio de las razones de la masa del hígado y la masa corporal total de un grupo de animales de laboratorio. Ratas macho Wistar destetadas fueron alimentadas diariamente con una dieta sólida ad libitum (Global Teklad) y se les dio a beber agua que contenía uno de los siguientes edulcorantes: 1) Fructosa, 15%; 2) Sacarosa, 10%; 3) Aspartame, 0.3%; 4) Sucralosa, 0.19%, y 5) Control, agua sin edulcorante. Después de 73 días, los animales fueron sacrificados y el tejido hepático fue removido. Se tenía información del volumen de agua consumido por día, cantidad de alimento y ganancia en masa corporal. Los resultados fueron comparados estadísticamente (p<0.05), mostrando que la fructosa en agua provocó la mayor ganancia de masa en las ratas. Las ratas que consumieron sacarosa tuvieron la menor ingesta de alimento y la ganancia de masa más baja, estadísticamente similar a los animales del grupo control. Los animales bajo estudio que tomaron agua con edulcorantes artificiales hipo-calóricos, aspartame y sucralosa, consumieron la misma cantidad de comida que los animales en el grupo control pero estaban más gordos que el control y que el grupo que consumió sacarosa, aunque menos pesados que los animales que tomaron agua con fructosa. El grupo que consumió fructosa mostró una tendencia a tener un radio masa hepática:masa corporal más alto aunque los resultados no fueron estadísticamente significativos respecto a los otros grupos. Una tendencia contraria en cuanto al radio masa hepática:masa corporal se notó en los grupos de ratas consumiendo los dos edulcorantes hipo-calóricos, aunque los valores tampoco fueron estadísticamente significativos. Estos resultados deben estudiarse más a fondo en experimentos de más largo plazo (250–300 días).
SUGARCANE PRODUCTION AND RESEARCH IN CHINA

By

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KEYWORDS: Industry, History, China, Research, Production.

Abstract

This paper describes the progress of the sugarcane industry in China, as well as the major characteristics of sugarcane production systems and R&D. Over the past 8 years, production area expanded by 47.87%, total sugarcane production increased by 79.54%, cane yield per hectare by 21.26% and annual sugar production by 83.12%. Sugar consumption in China has also grown steadily. Sugarcane was mainly grown in Central-South Guangxi, Southwest Yunnan, West of Guangdong and Northern Hainan. For energy production from sugarcane, national research projects have been carried out. Pilot study showed that the cost of ethanol production from sugarcane could be reduced to US$0.50/L, which was more economic than gasoline at US$70 per barrel. The problems facing the industry and their possible solutions are also discussed.

The history of sugarcane production in China

China is one of the original producers of sugarcane. Bamboo Cane (Saccharum sinense) and wild species (S. spontaneum) are widely distributed, from the North Qinling Mountains to the South Hainan Island. Sugarcane cultivation has a long history; since the late 4th century BC, China has used sugarcane to produce syrup.

Since the establishment of new China, sugarcane production has increased significantly. From 1949 to 2008, the total area of sugarcane plantation extended from 0.108 million to 1.475 million ha, cane production from 2.643 million to 113.0 million tonnes, cane yield per ha from 24 to 75 tonnes and total sugar production from 0.15 million to 13.697 million tonnes.

Sugarcane status of China

Major statistics for sugarcane production from 1997 to 2008 are listed in Table 1, and similar information for major production provinces from 2001 to 2008 in Table 2. In 2008, sugarcane plantation area was 1.521 million ha, which accounted for 71.4% of the total area for sugar plantations.

Total sugarcane production was 110.711 million tonnes, which produced 13.697 million tonnes of cane sugar. Compared with the 2001/2002 crushing season, production area expanded by 47.87%, total sugarcane production increased by 79.54%, cane yield per hectare by 21.26%, and annual sugar by 83.12% (Tables 1 and 2).

In December 2001, the State Council launched the Food and Nutrition Development Plan in China (2001–2010). This Plan aimed to increase sugar intake by 9 kg per person by 2010, which was equivalent to a total of 12 million tonnes of white sugar.

Before 2000, Chinese sugar consumption averaged about 8 Mt/y. It then increased to 10 Mt in 2003 and 11.4 Mt in 2004.

The average consumption of sugar per person per year in China was about 8.4 kg, which was among the lowest in the world. For sugar consumed in China, 72.6% was used in the food industry, 26.2% by households, and less than 1.2% for export. Sugar consumption has been increasing steadily due to the rapid development in the food, restaurant and catering industry (Table 1).
Table 1—Sugarcane industry in China from 1997–2008.

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (M ha)</td>
<td>1.058</td>
<td>1.149</td>
<td>1.012</td>
<td>0.975</td>
<td>1.029</td>
<td>1.092</td>
<td>1.174</td>
<td>1.205</td>
<td>1.214</td>
<td>1.318</td>
<td>1.521</td>
</tr>
<tr>
<td>Cane processed (M t)</td>
<td>64.461</td>
<td>69.119</td>
<td>58.871</td>
<td>56.995</td>
<td>66.499</td>
<td>83.071</td>
<td>76.552</td>
<td>69.369</td>
<td>66.199</td>
<td>87.713</td>
<td>114.790</td>
</tr>
<tr>
<td>Sugar output (%)</td>
<td>10.52</td>
<td>10.95</td>
<td>10.54</td>
<td>9.66</td>
<td>11.23</td>
<td>11.31</td>
<td>12.33</td>
<td>12.36</td>
<td>12.10</td>
<td>12.25</td>
<td>11.92</td>
</tr>
<tr>
<td>Cane/sugar ratio</td>
<td>9.51</td>
<td>9.13</td>
<td>9.49</td>
<td>10.35</td>
<td>8.90</td>
<td>8.84</td>
<td>8.11</td>
<td>8.09</td>
<td>8.26</td>
<td>8.16</td>
<td>8.40</td>
</tr>
<tr>
<td>Consumption (Mt)</td>
<td>8.30</td>
<td>8.00</td>
<td>8.10</td>
<td>8.50</td>
<td>9.15</td>
<td>10.00</td>
<td>11.40</td>
<td>10.50</td>
<td>10.80</td>
<td>12.50</td>
<td>13.50</td>
</tr>
</tbody>
</table>

Sugarcane growing areas in China

The major sugarcane production area in China is located between latitude 18.5° to 32°N and longitude 92° to 122°E that includes Guangxi, Yunnan, Guangdong, Hainan, Fujian, Taiwan, Zhejiang, Sichuan, Guizhou, Hunan and Jiangxi provinces (or Autonomous Regions). Before the late 1980s, coastal areas in southeastern China such as Guangdong and Fujian were the main sugarcane producing areas. Since then, sugarcane production gradually shifted to the west to more sustainable production. So the current major production areas include Guangxi, Yunnan, Guangdong and Hainan provinces. In 2007/2008 season, 9.37 million tonnes of sugar was produced in Guangxi, which was equal to 68.5% of total sugar production, the largest producer in China. Yunnan produced 2.163 million tonnes, or 15.8% of the total production, which made it the second largest. Sugar production in western Guangdong was 1.454 million tonnes per year, the third largest. The combined sugar production from these three provinces accounted for 94.8% of the total production in China. Dominant production regions in these provinces were central-south in Guangxi, southwest in Yunnan, western in Guangdong and northern in Hainan (Figure 1).

Fig. 1—Major sugar producing areas (shaded) in China
Main features of sugarcane production systems

There were about 5 million farms. The average farm size was only about 0.27 ha and produced an average of 18 t cane. Planting, weeding, cultivation, fertilising, spraying and harvesting were still done by hand. Fertiliser was used excessively, especially nitrogen, at three times the world average, while the usage efficiency was low. It resulted in soil acidification and degradation as well as pollution. Most of the sugarcane fields were dry slopes with infertile soil. The average available irrigation was below 20 percent irrigation. Rainfall distribution was uneven and seasonal natural disasters such as drought and frost happened frequently. All these had an adverse impact on sugarcane production. For example, the frost in 1998–1999 and the drought in 2005–2006 caused serious damage to sugar production. Sugarcane smut, ratoon stunting disease, mosaic and other diseases caused more than a 20 percent reduction in production. Borers and soil-borne pests (e.g. Dorysthenes granulosus, grub) were found in over 60% of sugarcane plantations, which caused the loss of sugar content of over 0.5%. Improper usage of pesticides polluted the environment. Varieties from Taiwan Sugar were grown in more than 70% of the total sugarcane plantation area, varieties bred in mainland China less than 30%.

In 2006–2007, China had 212 sugar mills, of which 90% were in Guangdong, Guangxi and Yunnan. They were able to process 780 000 tonnes of cane per day, 18.2% higher than the capacity at the beginning of this century. There were 17 sugar enterprises with daily processing capacity exceeding 10 000 t cane, such as South China Sugar Co., Guangxi Farming Co., Fengtang Biochemistry Co., Yingmao Sugar Co. and Zhanjiang Farming Co. Energy consumption for processing 100 t cane was equivalent to 4.97 t standard coal, which was 20.5% less than 2002 or the lowest in history. Processing of 1 tonne of cane consumed 30.86 kWh of power, 2.7% less than 2002. Ratio of white sugar to cane was 12.23%, 1.28% higher than the beginning of this century. The sugar industry saved energy and increased efficiency remarkably. The major statistics of the industry are presented in Tables 2 and 3.

Main institutes doing sugarcane R&D in China

In China, the major sugarcane research institutes are the Sugarcane Synthetic Institute of Fujian Agriculture and Forestry University, Guangzhou Sugarcane Industry Research Institute, Guangxi Sugarcane Institute and the Sugarcane Institute of Yunnan Academy of Agricultural Science.

The institute of Fujian Agriculture and Forestry University has undertaken sugarcane research and development for 54 years. It established the first Sugarcane Branch of the National Sugar Crop Improvement Centre and managed a number of research laboratories and organisations; notably, the Key Laboratory of Sugarcane Genetics and Improvement of the Ministry of Agriculture, Cane Sugar Inspection Centre of the Ministry of Agriculture, Sugarcane Society of the Chinese Crop Society and National Sugarcane Variety Accreditation Committee. The Institute had the authority to award masters and PhD degrees and also hosted post-doctoral workers.

Professor Chen Rukai, the discipline leader, is a member of the Science and Technology Commission of the Ministry of Agriculture, and a chief scientist in sugarcane. In his institute, there are 6 professors who are national-level scientists in sugarcane research and 13 associate professors. The Institute has 30 staff and 30 to 40 graduates, and it is engaged in sugarcane research and development including genetics and improvement for sugar and energy sugarcane, nutrition management, pest control, agricultural mechanisation and industrial economy.

Guangzhou Sugarcane Industry Research Institute has undertaken sugarcane research and development for 50 years. It was under the former Ministry of Light Industry, and now it is the National Centre for Sugar Quality Inspection, Guangdong Branch of National Sugarcane Improvement Centre, and National Sugarcane Hybridisation Station in Hainan.
Table 2—Major technological indices of China's sugarcane growing areas in recent years.

<table>
<thead>
<tr>
<th></th>
<th>01/02</th>
<th>02/03</th>
<th>03/04</th>
<th>04/05</th>
<th>05/06</th>
<th>06/07</th>
<th>07/08</th>
<th>07/08</th>
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<tbody>
<tr>
<td><strong>Average</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area million ha</td>
<td>1.029</td>
<td>1.092</td>
<td>1.174</td>
<td>1.205</td>
<td>1.214</td>
<td>1.318</td>
<td>1.522</td>
<td>100.00</td>
</tr>
<tr>
<td>Total yield (Mt)</td>
<td>63.934</td>
<td>72.365</td>
<td>77.470</td>
<td>80.535</td>
<td>79.848</td>
<td>89.910</td>
<td>114.787</td>
<td>100.00</td>
</tr>
<tr>
<td>Cane yield (t/ha)</td>
<td>62.10</td>
<td>66.30</td>
<td>66.00</td>
<td>66.90</td>
<td>65.70</td>
<td>68.25</td>
<td>75.30</td>
<td>100.00</td>
</tr>
<tr>
<td>Total sugar yield/%</td>
<td>7.470</td>
<td>9.396</td>
<td>9.436</td>
<td>8.571</td>
<td>8.008</td>
<td>10.745</td>
<td>13.670</td>
<td>100.00</td>
</tr>
<tr>
<td><strong>Guangxi</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area (ha)</td>
<td>508 000</td>
<td>573 333</td>
<td>684 000</td>
<td>684 000</td>
<td>766 667</td>
<td>814 000</td>
<td>966 667</td>
<td>100.00</td>
</tr>
<tr>
<td>Total cane yield (Mt)</td>
<td>32.299</td>
<td>39.266</td>
<td>46.931</td>
<td>47.294</td>
<td>52.862</td>
<td>57.524</td>
<td>76.510</td>
<td>100.00</td>
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<tr>
<td>Cane yield (t/ha)</td>
<td>63.60</td>
<td>68.55</td>
<td>68.55</td>
<td>69.15</td>
<td>69.00</td>
<td>70.65</td>
<td>79.05</td>
<td>100.00</td>
</tr>
<tr>
<td>Total sugar yield %</td>
<td>4.430</td>
<td>5.610</td>
<td>5.880</td>
<td>5.320</td>
<td>5.377</td>
<td>7.068</td>
<td>9.372</td>
<td>100.00</td>
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<tr>
<td><strong>Yunnan</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Area (ha)</td>
<td>266 667</td>
<td>273 333</td>
<td>260 000</td>
<td>286 667</td>
<td>244 860</td>
<td>285 627</td>
<td>313 333</td>
<td>100.00</td>
</tr>
<tr>
<td>Total cane yield (Mt)</td>
<td>14.683</td>
<td>15.942</td>
<td>15.087</td>
<td>17.256</td>
<td>13.592</td>
<td>16.695</td>
<td>17.960</td>
<td>100.00</td>
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<tr>
<td>Cane yield (t/ha)</td>
<td>55.05</td>
<td>58.35</td>
<td>58.05</td>
<td>60.15</td>
<td>55.50</td>
<td>58.50</td>
<td>57.30</td>
<td>100.00</td>
</tr>
<tr>
<td>Total sugar yield %</td>
<td>1.4350</td>
<td>1.8900</td>
<td>1.9501</td>
<td>1.5920</td>
<td>1.4130</td>
<td>1.8315</td>
<td>2.1625</td>
<td>100.00</td>
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<tr>
<td><strong>Guangdong</strong></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area (ha)</td>
<td>149 333</td>
<td>142 667</td>
<td>126 667</td>
<td>135 333</td>
<td>126 367</td>
<td>138 000</td>
<td>166 667</td>
<td>100.00</td>
</tr>
<tr>
<td>Total cane yield (Mt)</td>
<td>11.079</td>
<td>10.9367</td>
<td>9.203</td>
<td>9.329</td>
<td>9.432</td>
<td>10.907</td>
<td>14.490</td>
<td>100.00</td>
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<tr>
<td>Cane yield (t/ha)</td>
<td>74.25</td>
<td>76.65</td>
<td>72.60</td>
<td>73.35</td>
<td>75.60</td>
<td>78.05</td>
<td>87.00</td>
<td>100.00</td>
</tr>
<tr>
<td>Total sugar yield %</td>
<td>1.044</td>
<td>1.165</td>
<td>0.985</td>
<td>1.121</td>
<td>0.922</td>
<td>1.279</td>
<td>1.453</td>
<td>100.00</td>
</tr>
<tr>
<td><strong>Hainan</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area (ha)</td>
<td>60 000</td>
<td>60 000</td>
<td>63 333</td>
<td>70 000</td>
<td>60 000</td>
<td>60 667</td>
<td>80 000</td>
<td>100.00</td>
</tr>
<tr>
<td>Total cane yield (Mt)</td>
<td>3.166</td>
<td>3.460</td>
<td>3.685</td>
<td>4.185</td>
<td>2.789</td>
<td>3.517</td>
<td>4.400</td>
<td>100.00</td>
</tr>
<tr>
<td>Cane yield (t/ha)</td>
<td>52.80</td>
<td>57.60</td>
<td>58.20</td>
<td>59.85</td>
<td>58.05</td>
<td>55.05</td>
<td>73.11</td>
<td>100.00</td>
</tr>
<tr>
<td>Total sugar yield %</td>
<td>0.3040</td>
<td>0.420</td>
<td>0.408</td>
<td>0.385</td>
<td>0.178</td>
<td>0.375</td>
<td>0.517</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Source: Chinese Sugar Industry Association

Director Li Qiwei is engaged in sugarcane breeding and cultivation and is responsible for the Guangdong Sugarcane Society. He is also the executive member of China's Sugarcane Special Committee.

The institute has 4 national-level scientists, 30 researchers and associate researchers, and a staff of 120 members who work in sugarcane genetics and breeding, cultivation, plant protection, sucrose and ethanol processing, and sugar quality inspection. It is an assistant institute for the national projects undertaken by Fujian Agriculture and Forestry University.

Guangxi Sugarcane Institute is the Sugarcane Research Centre of the Chinese Academy of Agricultural Sciences, Sugarcane Variety Inspection Centre of Ministry of Agriculture, and Guangxi Branch of National Sugar Improvement Centre. It has 3 national-level experts, 20 researchers and associate researchers, and a staff of 160 members engaged in sugarcane breeding, cultivation and pest control. It is also in charge of two prepared projects for the National Science and Technology support plan, as an assistant institute for national projects undertaken by Fujian Agriculture and Forestry University.

The Institute of Yunnan Academy of Agricultural Sciences is the Yunnan Branch of National Sugar Crop Improvement Centre, and National Sugarcane Germplasm Resources Base is an assistant institute for national projects undertaken by Fujian Agriculture and Forestry University. Director Zhang Yuebin is engaged in sugarcane cultivation research. The institute has 3 national-level experts, 20 researchers and associate researchers, and a staff of 60 members.
Table 3—Technological indices of China's sugar processing industry in recent years.

<table>
<thead>
<tr>
<th>Index</th>
<th>2001/02</th>
<th>2002/03</th>
<th>2003/04</th>
<th>2004/05</th>
<th>2005/06</th>
<th>2006/07</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane processed (Mt)</td>
<td>66.499</td>
<td>83.071</td>
<td>76.552</td>
<td>69.369</td>
<td>66.169</td>
<td>87.713</td>
</tr>
<tr>
<td>Sucrose content of cane %</td>
<td>13.56</td>
<td>13.25</td>
<td>14.30</td>
<td>14.28</td>
<td>13.95</td>
<td>14.56</td>
</tr>
<tr>
<td>Sugar output (Mt)</td>
<td>7.613</td>
<td>9.449</td>
<td>9.450</td>
<td>8.573</td>
<td>8.022</td>
<td>10.745</td>
</tr>
<tr>
<td>Recovery in refining %</td>
<td>88.66</td>
<td>88.92</td>
<td>89.61</td>
<td>89.48</td>
<td>88.18</td>
<td>88.96</td>
</tr>
<tr>
<td>Overall recovery/%</td>
<td>85.48</td>
<td>85.30</td>
<td>85.90</td>
<td>85.80</td>
<td>85.09</td>
<td>85.38</td>
</tr>
<tr>
<td>Percentage of sugar output/%</td>
<td>11.68</td>
<td>10.95</td>
<td>12.34</td>
<td>12.36</td>
<td>12.13</td>
<td>12.23</td>
</tr>
<tr>
<td>Energy consumption as t coal equivalent per 100 t cane</td>
<td>6.43</td>
<td>6.25</td>
<td>5.81</td>
<td>6.00</td>
<td>6.23</td>
<td>4.97</td>
</tr>
</tbody>
</table>

To centralise the management of scientific research and prevent repetition at a low level, the Ministry of Agriculture and Ministry of Finance has appointed a number of scientists nationwide to build a national sugarcane industrial technology system under the guarantee of retaining the current administrative relationship.

The system is divided into two layers, including one national sugarcane industrial technology research and development centre and 15 extension stations. Based on the Fujian Agriculture and Forestry University, the research and development centre consists of 5 programs.

They are: sugarcane genetics and improvement with 6 scientists, nutrition and cultivation with 4 scientists, plant protection with 5, facilities and equipments with 3, and the processing and industrial economy with 2. Major participants are the Fujian Agriculture and Forestry University, Guangzhou Sugarcane and Sugar Industry Institute, Guangxi Sugarcane Institute, Yunnan Sugarcane Research Institute and South China Agricultural University.

Professor Chen Rukai has been appointed as the chief scientist. Lin Yanquan, Li Qiwei, Huang Chenghua, Ou Yinggang and Zheng Chuanfang have been appointed as program leaders. Meanwhile, 15 extension stations have been established based on provincial and district level that are based on Nanning, Chongzuo, Laibin, Liuzhou, Bose, Beihai, Nongken of Guangxi; Suixi, Zhanjiang of Guangdong; Kaiyuan, Lincang, Baoshan of Yunnan; Zhangzhou of Fujian; Nankang of Jiangxi; Zhanzhou of Hainan.

Fifteen directors have been appointed for the stations for a 5-year term with funds from government. In the current administration system, the projects are structured in a vertical fashion. The cooperation among different sectors of the industry, regions and disciplines should accelerate sugarcane industrial technology progress.

Prospects for future: further expansion

From 1996 to 2007, China’s sugar consumption increased from 7.8 million to 13.4 million tonnes, with an annual increase of 0.46 million tonnes. Based on this rate, the domestic sugar demand will reach 17 million tonnes by 2015, of which 13 million tonnes will come from cane sugar, 2.5 from corn, and 1.5 from sugar beet. This requires an extra 2 million tonnes of cane sugar based on the 10.75 million tonnes of cane sugar production in 2007. It is predicted that by 2015 total sugarcane area would be around 1.6 million hectares, cane yield 75 tonnes per hectare and total cane yield 12 million tonnes. With this prediction, the targeted sugar production could be met.

In China, the ‘Renewable Energy Law’ has come into effect, and the standards of ‘Denaturalised Fuel Ethanol’ and ‘Gasoline Alcohol’ have been established. The 863 Nation High Technology Project on energy sugarcane and sugarcane ethanol has started and is making progress. The concept of diversified ethanol materials has been extremely popular. The cost of ethanol is $0.25/L in Brazil, $0.50/L in USA, also $0.50 /L in China. Ethanol at $0.50/L is more cost-effective than gasoline at $70 per barrel in the market. In South China, sugarcane does not compete with grain crops for land and water. In Yunnan, Guangxi, Guangdong, Fujian and Hainan, there are still about
0.67 million ha of land that can be used to grow energy sugarcane, and it could produce 5.88 million tonnes of sucrose or 3.84 million tonnes of ethanol. It is beneficial to the environment because it will reduce pollution caused by automobiles. The development of the sugarcane ethanol industry will optimise the production structure of the sugarcane industry, stabilise the sugarcane growing areas, and increase farmers’ job opportunities and incomes.

The Chinese sugar industry produces 4.40 million tonnes of molasses annually, which can be used to produce 800,000 tonnes of fuel ethanol. It also produces 26.57 million tonnes of bagasse with 50% water content. Bagasse can be used to produce 8 million tonnes of paper pulp or a 1600 MW power plant to produce 11.2 billion kWh of green power per year. The cellulose and hemicellulose of bagasse are high quality raw materials for future industrial use to produce fuel ethanol.

In the coming 5 years, the major tasks in China sugarcane research and development will be as follows:

- Selection of new sugarcane varieties with high yield, optimal quality, resistance to diseases and pests, strong ratooning ability for the dominant sugarcane growing areas; this is necessary in order to solve present problems in production such as few varieties, same maturity periods, low sugar yield, deficiencies in rural labour forces, lack of machinery, severe diseases and pests, effects of toxic pesticides on environment, high production costs.

- A system of production technologies including mechanisation, water-fertiliser management, intercropping, diseases and pest control, along with more varieties with a wide range of maturing periods. Production trials and demonstrations in large areas of these technologies should be conducted in different ecological regions, from which to form a practical production system with high efficiency and low cost.

- Development and demonstration of techniques on water use efficiency, intercropping systems (sugarcane and leguminous), harvest machinery systems, and the integration of cultivation and varieties

- Research from the viewpoint of the sugarcane industry facing the challenge of growing population, resource and environmental pressures.
RECHERCHE ET PRODUCTION DE LA CANNE À SUCRE EN CHINE

Par

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Mots Clés: Industrie, Histoire, Chine, Recherche, Production.

Résumé
Cet article décrit l'état d'avancement de l'industrie de la canne à sucre en Chine, les principales caractéristiques des systèmes de production, ainsi que la Recherche et le Développement. Au cours des 8 dernières années la superficie de production s’est étendu par 47.87 %, la production totale de la canne à sucre a augmenté de 79.54 %, le rendement de canne à l'hectare de 21.26 % et la production de sucre annuelle de 83.12 %. La consommation de sucre en Chine a également connu une croissance constante. La canne à sucre a été principalement cultivée au Centre-Sud Guangxi, au Sud-Ouest de Yunnan, à l’Ouest de Guangdong et au Nord de Hainan. Pour la production d'énergie à partir de la canne à sucre, les projets nationaux de recherche ont été effectués. Une étude pilote a montré que le coût de production de l’éthanol à partir de la canne à sucre pourrait être réduit à 0,50 $ US/L, qui était plus économique que l'essence à US$ 70 le baril. Les problèmes auxquels fait face l'industrie et les solutions possibles sont également abordées.

PRODUCCION E INVESTIGACIÓN DE CAÑA DE AZÚCAR EN CHINA

Por

CHEN RUKAI y ZHAONIAN YUAN
Key Lab of Genetic Improvement for Sugarcane, Ministry of Agriculture, Fuzhou 350002
yzn05@sina.com

PALABRAS CLAVE: Industria, Historia, China, Investigación, Producción.

Resumen
Este trabajo describe el progreso de la industria azucarera en China, así como las principales características de los sistemas de producción y de investigación y desarrollo (R&D en inglés). Durante los últimos 8 años, el área total de producción se expandió en 47.87%, la producción total de azúcar se incrementó en 79.54%, el rendimiento de caña por hectárea mejoró en un 21.26% y la producción anual de azúcar en 83.12%. El consumo de azúcar en China también ha tenido un crecimiento estable. Los cultivos de caña de azúcar estaban principalmente en la Región Centro-Sur de Guangxi, al suroeste de Yunnan, al Oeste de Guangdong y el norte de Hainan. Se han realizado proyectos de investigación a nivel nacional para la producción de energía proveniente de la caña. Un estudio piloto demostró que el costo de la producción de etanol de caña podía reducirse a USD 0.50/L, lo que es más económico que el precio de la gasolina a USD 70 por barril. Los problemas que enfrenta la industria y sus posibles soluciones también son discutidos.