
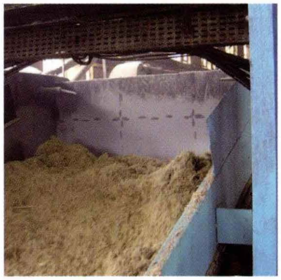

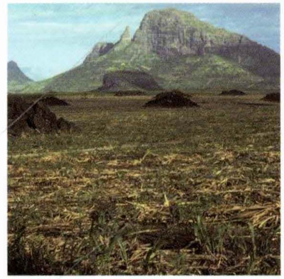




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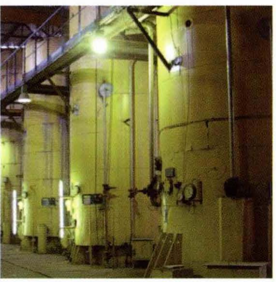
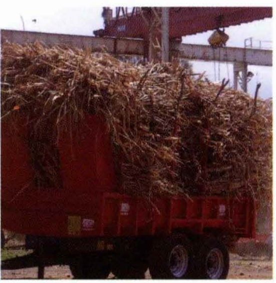
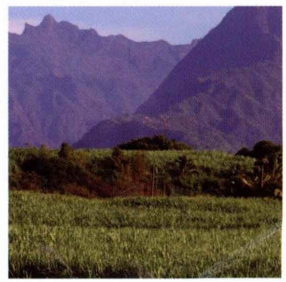


Sugarcane Annual Report




2005-2006



CIRAD

Sugarcane annual report

2005-2006

The Agricultural Research Centre for International Development, CIRAD, is a French agricultural research centre working for development in developing countries and the French overseas regions. Most of its research is conducted in partnership.

CIRAD has chosen sustainable development as the cornerstone of its operations worldwide. This means taking account of the long-term ecological, economic and social consequences of change in developing communities and countries.

CIRAD contributes to development through research and trials, training, dissemination of information, innovation and appraisals. Its expertise spans the life sciences, human sciences and engineering sciences and their application to agriculture and food, natural resource management and society.

CIRAD has three research departments: Biological Systems (BIOS), Performance of Tropical Production and Processing Systems (PERSYST), and Environments and Societies (ES). This includes 59 units: 32 internal research units (UPR), 4 service units (US), 20 joint research units (UMR), and 3 international research units (URP).

It employs 1 825 people, including 1047 senior staff members of whom 856 are scientists, and has an annual operating budget of 203 million euros.

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Foreword

CIRAD is now able to effectively focus on specific scientific issues through its new three-department organization, incorporating 62 research units. In 2005-2006, cross-sectional research was carried out on sugarcane topics by nine research units. The same year, the Directorate of the CIRAD Annual Crops department asked me to serve as the Centre's Sugarcane Project Coordinator. As most of the research units are highly specialized, the overall aim was to urge collaborations between teams on sugarcane issues in multidisciplinary and often consolidated research projects. It is essential to maintain a subsector-based portal at CIRAD for all of our public and private, technical and financial partners. I hope that this 2005-2006 Sugarcane Annual Report clearly illustrates this dynamic multidisciplinary approach to sugarcane research at CIRAD.

It is crucial to promote and confirm the relevance of CIRAD sugarcane research through a broad range of publications. The performance of our research units was assessed in this respect by French and European scientific experts and users from developing countries. Such assessments ensure effective advancement of scientific research—sometimes questioning the relevance of certain research topics or highlighting new ones, such as sugarcane and the environment, the use of biomass to synthesize bioproducts for energy and pharmaceutical use, and biomaterials. We must be thoroughly prepared to meet these new challenges.

Some of CIRAD's sugarcane research teams are located in French overseas departments. New international cooperations have been set up. Scientists are often posted in institutions in foreign countries, but expertise assignments and participation in international projects (e.g. projects of the International Consortium for Sugarcane Biotechnology) are keys to ensuring CIRAD's presence in the industrial sector and in major scientific conferences.

We have also changed the layout of this 2005-2006 Sugarcane Annual Report. Sugarcane research activities at CIRAD are outlined in full detail. Some research activities that have generated important or original results are also presented. With this new design, different projects carried out each year are presented, thus illustrating the dynamics of research under way on sugarcane at CIRAD.

I hope this report will meet all readers' expectations, while providing decision makers, professional stakeholders, trainers and other interested people with access to our scientific and technical results.

François-Régis Goebel,
Sugarcane Project Coordinator,
CIRAD

↗ Contents ↖

Sugarcane research activities at CIRAD in 2005-2006

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Sugarcane research activities at CIRAD in 2005-2006

In 2005-2006, many sugarcane projects were conducted by nine research units at CIRAD (Table 1). Most of these were multidisciplinary initiatives involving several research teams.

Table 1.

Sugarcane-oriented research activities at CIRAD in 2005-2006.(↗ = some of these results are also covered in the *Key Projects and Results* section)

	Research project title	Topic and discipline	Research unit involved	Project leader	Location
↗ p. 17	Sugar mill supply organization	Agronomy	UPR 5	Caroline Lejars	Réunion
↗ p. 20	Sugarcane supply simulation model (MAGI)	Informatics	UPR 13	Sandrine Auzoux	Montpellier
	Modeling cane supply to sugar mills in South Africa	Agronomy	UPR 43	Pierre-Yves Le Gal	Montpellier South Africa
	Cane quality	Agronomy	UPR 5	Caroline Lejars	Réunion
	Modeling sugar content in Réunion	Biostatistics	UPR 13	Sabine Laurent (PhD thesis)	Montpellier
	Typology of a sugarcane-growing area (ZECAS)	Informatics	UPR 13	Jean Parriaud	Montpellier
↗ p. 24	Technical and economic guidelines for sugarcane farms	Economy	UPR 5	Jérôme Masson	Réunion
↗ p. 29 p. 35	Remote-sensing support for sugar-cane area management	Agronomy Remote sensing	UPR 5, UMR TETIS	Agnès Bégué, Valentine Lebourgeois (PhD thesis)	Réunion Montpellier

*** Names of CIRAD Research Units (UPR) and Joint Research Units (UMR):**
UPR 5, Sugarcane Farming Systems - UR 75, Genetic Improvement of Vegetatively Propagated Crops - UPR 13, Decision Support and Biostatistics - UPR 43, Innovation and Dynamics of Farming Systems - UPR 78, Environmental Risks and Recycling - UMR BGPI, Biology and Genetics of Plant-Pathogen Interactions for Integrated Protection, CIRAD, Agro.M, INRA, Montpellier, France - UMR PVBMT, Plant Communities and Biological Invaders in Tropical Environments, CIRAD, Université de La Réunion, Réunion - UMR PIA, Polymorphisms of Interest in Agriculture, CIRAD, Agro.M, INRA, Montpellier, France – UMR TETIS, Spatial Information and Analysis for Territories and Ecosystems, CIRAD, CEMAGREF, ENGREF, Montpellier, France.

Table 1 (cont'd).

Sugarcane-oriented research activities at CIRAD in 2005-2006.(↗ = some of these results are also covered in the *Key Projects and Results* section)

	Research project title	Topic and discipline	Research unit involved	Project leader	Location
	Regional cooperation: geographical information systems and remote sensing in OECS countries	Agronomy Remote sensing Geographical information systems	UPR 5	Pierre Todoroff	Guadeloupe
	Sugarcane growth and harvest forecasting model (MOSICAS)	Agronomy Agrophysiology	UPR 5	Jean-François Martiné	Réunion
	Modeling sugarcane growth and development of decision-support tools	Agronomy Agrophysiology	UPR 5	Pierre Todoroff	Guadeloupe
↗ p. 36	Environmental impact of sugarcane cropping	Agronomy	UPR 5	Christophe Poser	Réunion
	Biomass development	Agronomy By-product development	UPR 5	Denis Pouzet	Guadeloupe
↗ p. 38	Use of filter mud in sugarcane fields	Agronomy Soil biology By-product development	UPR 78	Denis Montange Thabit Elsayed (PhD thesis)	Sudan Montpellier
↗ p. 39	Assessment of world bagasse production. Energy potentia	Agronomy By-product development	UPR 5	Pierre Langellier	Montpellier
	Agronomic features of sugarcane in highlands (Réunion)	Agronomy	UPR 5	Christophe Poser	Réunion
	Soil cover, cultivars, weed infestation and plant spacing	Agronomy	UPR 5	Denis Pouzet	Guadeloupe
	Weed management: herbicide certification	Weed management	UPR 5	Pascal Marnotte	Montpellier Réunion Guadeloupe Martinique
	Agro-pedology and fertilization	Agronomy	UPR 5	Marinus Brouwers	Montpellier
↗ p. 40	Training on Racin'situ, a field root study method	Agronomy	UPR5	Jean-Louis Chopart	Senegal Réunion Montpellier
	Technical assistance to the Senegalese sugar company	Agronomy Water management	UPR 5	Daniel Marion	Senegal

Table 1 (cont'd).

Sugarcane-oriented research activities at CIRAD in 2005-2006.(↗ = some of these results are also covered in the *Key Projects and Results* section)

	Research project title	Topic and discipline	Research unit involved	Project leader	Location
	Quality control of the meteorological network managed by CIRAD	Agronomy Water management	UPR 5	Roland Pirot	Réunion
↗ p. 41	RAINETTE agro-meteorological project	Agronomy Bioclimatology	UPR 5	Pierre Todoroff	Guadeloupe
↗ p. 41	Meteorological database portal in Guadeloupe (RAINETTE project)	Informatics	UPR 13	Jean-Baptiste Laurent	Montpellier
↗ p. 42	Water management, decision support	Agronomy	UPR 5	Pierre Langellier	Montpellier
↗ p. 43	Analysis of irrigation variability	Agronomy Water management	UPR 5	Roland Pirot	Réunion
	Effects of water supply rationing during the first third of the cropping cycle	Agronomy Water management	UPR 5	Jean-Louis Chopart	Réunion
	OSIRI-RUN: an irrigation consulting tool	Agronomy Water management	UPR 5	Jean-Louis Chopart	Réunion
	Simulating irrigation water consumption with M-CIDER	Agronomy Water management	UPR 5	Jean-Louis Chopart	Réunion
	Mechanized harvesting in Réunion	Agronomy Mechanization of sugarcane areas	UPR 5	Dany Deurveilher	Réunion
	Mechanization of the sugarcane-cropping area in Guadeloupe	Agronomy Mechanization of sugarcane areas	UPR 5	Jean-Cyril Dagallier	Guadeloupe
	Costs, organization and management of sugarcane transportation	Agronomy Mecanisation of the sugarcane cropping area	UPR 5	Jean-Cyril Dagallier	Guadeloupe
	Preliminary cultivation management (alternative techniques)	Agronomy Mecanisation of the sugarcane cropping area	UPR 5	Jean-Cyril Dagallier	Guadeloupe
↗ p. 44	Training modules on agricultural machinery use and enhanced land management improvement	Agronomy Mechanisation of the sugarcane cropping area	UPR 5	Jean-Cyril Dagallier	Réunion Guadeloupe Martinique
	Genetic resource management	Varietal improvement	UPR 75	Danièle Roques	Guadeloupe
	Sugarcane breeding and hybridization	Varietal improvement	UPR 75	Danièle Roques	Guadeloupe
	Sugarcane breeding	Varietal improvement	UPR 75	Danièle Roques	Guadeloupe

Table 1 (cont'd).

Sugarcane-oriented research activities at CIRAD in 2005-2006.(↗ = some of these results are also covered in the *Key Projects and Results* section)

	Research project title	Topic and discipline	Research unit involved	Project leader	Location
	Parental stock assessment: progeny tests	Varietal improvement	UPR 75	Danièle Roques	Guadeloupe
↗ p. 46	Regional participatory selection: breeding and dissemination of improved varieties	Varietal improvement	UPR 75	Philippe Oriol	Guadeloupe
	Calibration of sugarcane cultivars for the MOSICAS growth model	Agronomy	UPR 5	Denis Pouzet	Guadeloupe
	Diversification and enrichment of the range of sugarcane varieties: variety exchanges with foreign partners	Varietal improvement	UPR 75	Philippe Oriol, Danièle Roques, Robert Domaingue	Guadeloupe Montpellier
	Production of disease-free plants	Varietal improvement	UPR 75	Danièle Roques	Guadeloupe
	Stock-plant nursery management	Varietal improvement	UPR 75	Jean-Claude Efile	Guadeloupe
↗ p. 49 p. 51	Sugarcane quarantine: data management, disease elimination, detection and diagnosis	Crop protection Phytopathology	UMR BGPI	Jean-Claude Girard	Montpellier
	Sugarcane quarantine information system	Informatics	UPR 13	Michel Giner	Montpellier
	Genetic analysis of useful traits	Varietal improvement Genome analysis	UPR 75	Jean-Yves Hoarau	Guadeloupe
↗ p. 52	Analysis of physiological factors associated with water stress tolerance	Varietal improvement	UPR 75	Danièle Roques, Robert Domaingue	Guadeloupe Montpellier
	Assessment of CERF sugarcane varieties for resistance to gumming disease and leaf scald in Réunion	Crop protection Phytopathology	UMR PVBMT	Laurent Costet	Réunion
	Pest and disease monitoring and control in the CERF quarantine unit in Réunion	Crop protection Phytopathology	UMR PVBMT	Laurent Costet	Réunion
	Sugarcane disease monitoring in Guadeloupe and the West Indies	Pest and disease management Phytopathology	UPR 75	Jean-Heinrich Daugrois	Guadeloupe

Table 1 (cont'd).

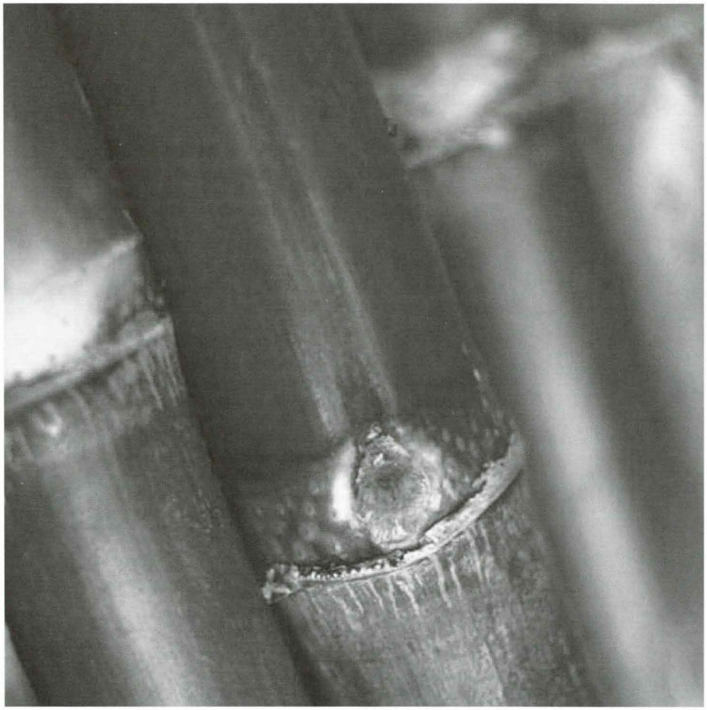
Sugarcane-oriented research activities at CIRAD in 2005-2006.(↗ = some of these results are also covered in the *Key Projects and Results* section)

	Research project title	Topic and discipline	Research unit involved	Project leader	Location
	Analysis of pest resistance factors: sugarcane pathology and varietal improvement support in Guadeloupe	Pest and disease management Phytopathology	UPR 75	Jean-Heinrich Daugrois	Guadeloupe
↗ p. 55	Role of silicon in sugarcane resistance to the African stalk borer *Eldana saccharina*	Crop protection Entomology	UPR 5	Régis Goebel	Montpellier South Africa
	Survey on damage caused by the African stalk borer *Eldana saccharina* in South Africa	Crop protection Entomology	UPR 5	Régis Goebel	Montpellier South Africa
	Biological control of the sugarcane white grub *Hoplochelus marginalis*	Crop protection Entomology	UPR 5	Bernard Vercambre	Réunion
	Biological control of the sugarcane spotted stemborer *Chilo sacchariphagus* using *Trichogramma* parasitoids	Crop protection Entomology	UPR 5	Régis Goebel	Montpellier Réunion
↗ p. 58	Use of sugarcane germplasm to enhance resistance to the sugarcane spotted stemborer *Chilo sacchariphagus*	Crop protection Entomology Varietal improvement	UMR PVBMT	Samuel Nibouche	Réunion
	Genetics and molecular analysis of the pathogenicity of phytopathogenic bacteria	Crop protection Phytopathology	UMR BGPI	Philippe Rott	Montpellier
	Genetic diversity and variation in the pathogenicity of *Xanthomonas* pathogens	Crop protection Phytopathology	UMR PVBMT	Laurent Costet	Réunion
↗ p. 61	Sugarcane leaf scald: genetic diversity and variation in the pathogenicity of *Xanthomonas albilineans*	Crop protection Phytopathology	UPR 75, UMR BGPI	Patrice Champoiseau (PhD thesis) Jean-Heinrich Daugrois	Montpellier Guadeloupe
	Airborne transmission of *Xanthomonas albilineans*	Crop protection Phytopathology	UPR 75, UMR BGPI	Jean-Heinrich Daugrois	Guadeloupe Réunion
	Sugarcane leaf scald: albicidin biosynthesis pathways	Crop protection Phytopathology	UMR BGPI	Eric Vivien	Montpellier
↗ p. 63	Sugarcane yellow leaf: characterization of genetic diversity and variation in the pathogenicity of *Sugarcane yellow leaf virus*	Crop protection Phytopathology	UMR BGPI	Philippe Rott Youssef Abu Ahmad (PhD thesis)	Montpellier

Table 1 (cont'd).

Sugarcane-oriented research activities at CIRAD in 2005-2006.(↗ = some of these results are also covered in the *Key Projects and Results* section)

	Research project title	Topic and discipline	Research unit involved	Project leader	Location
	Epidemiology of *Sugarcane yellow leaf virus* and sugarcane resistance mechanisms	Crop protection Phytopathology	UPR 75	Jean-Heinrich Daugrois Carine Edon (PhD thesis)	Guadeloupe
	Genetic diversity of the smut-inducing fungus *Ustilago scitaminea*	Genome analysis	UMR PIA, UMR PVBMT	Angélique d'Hont	Montpellier Réunion
↗ p. 65	Genetic determination of resistance to smut	Genome analysis	UMR PVBMT, UMR PIA	Louis-Marie Raboin (PhD thesis)	Montpellier Réunion
	Genetic analysis of disease resistance: diversity in sources of brown rust resistance	Genome analysis	UMR PVBMT, UMR PIA	Louis-Marie Raboin	Réunion Montpellier
↗ p. 66	Positional cloning of the *Bru1* brown rust resistance gene	Genome analysis	UMR PIA, UMR PVBMT	Angélique d'Hont Loïc Le Cunff (PhD thesis)	Montpellier Réunion
	Characterisation of linkage disequilibrium in sugarcane	Genome analysis	UMR PVBMT, UMR PIA	Louis-Marie Raboin	Réunion Montpellier
↗ p. 23	Publication of agricultural handbooks	Agronomy	UPR 5 UPR 75 UPR 78		Réunion Guadeloupe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Key Projects and Results

Sugarcane grower payment systems: simulation and case study

C. Lejars
UPR 5 Sugarcane Farming Systems

Studies carried out between 2002 and 2004 by CIRAD, in collaboration with the South African Sugar Research Institute (SASRI) and the French Institut national de la recherche agronomique (INRA), revealed that during a milling season 1-5% more sugar could be produced by implementing a sugarcane supply organization method that better accounts for cane quality variability within sugarcane-growing areas (Le Gal *et al.*, 2003; Lejars *et al.*, 2003; Lejars *et al.*, 2005)[1]. However, the impact of reorganizing supplies according to quality varies according to growers' income. When setting up new supply organization methods, it is thus essential to redistribute the added value fairly throughout the sector and to develop tailored payment systems.

Current sugarcane payment systems were evaluated first, and then a simulation tool was designed to test the joint effect of payment systems and supply methods. Finally, case studies were carried out in Réunion and South Africa to test the effects of changing payment systems.

→ Assessment of payment systems in 18 sugar-producing countries

Payment systems were studied in 18 sugar-producing countries (Lejars, 2005)[2] according to three functions:
– serving as a quality incentive vector
– promoting supply flow regularity
– providing a way to share added value from the sector between millers and growers, and between growers.

The results showed how each system component could influence the strategies of stakeholders in the sector (growers, millers, hauliers) and how the system reconciles (or not) the interests of all stakeholders. They also revealed that income has an impact on actual sugarcane supply regularity at mills and on the quality of the delivered supply.

1
Lejars C., Le Gal P.Y., Meyer E., Lyne P., Auzoux S., Siegmund B., 2005. Improved profitability by re-organising mill supply: a decision support approach: un enfoque de apoyo de decisions. *In* International Society of Sugar Cane Technologists Proceedings of the XXV Congress, 30 January - 4 February 2005, Guatemala. Ed. Hogarth, Guatemala, Atagua, vol. 2, p. 20-25. ISBN 99922-2-211-5.
Le Gal P.Y., Lejars C., Auzoux S., 2003. MAGI: a simulation tool to address cane supply chain management issues. *In* Proceedings of the Annual Congress of the South African Sugar Technologists' Association (SASTA), Mount Edgecombe, South Africa, 19-22 August 2003. Proceedings of the South African Sugar Technologists' Association 77: 555-565. ISSN 1028-3781.
Lejars C., Letourmy P., Laurent S., 2003. Building and assessing mill supply scenarios based on cane quality variations: example of Reunion Island. *In* Proceedings of the Annual Congress of the South African Sugar Technologists' Association (SASTA), Mount Edgecombe, South Africa, 19-22 August 2003. Proceedings of the South African Sugar Technologists' Association 77: 580-590. ISSN 1028-3781.

→ Tool designed to assess the effects of payment systems on growers' income

A simulation tool (Figure 1) was developed in Excel® to assess the effects of modifying grower payment systems and growers' quotas. This model has several functions:

– calculating growers' income (individuals or groups) for different payment systems
– analysing how added value generated by the sector is reallocated to growers. The results obtained can be analysed according to the farm type
– testing the impact of quota modifications on growers' income for a given payment system
– assessing the impact of payment systems on value sharing between growers and commercial stakeholders.

From a practical standpoint, this model generates responses to realistic questions:
– How does modifying a quality parameter used in a payment system affect growers' income?
– What is the impact of switching from an absolute to a relative payment system?
– What is the impact of modifying growers' weekly cane delivery quantities on their income for a given payment system?

→ Payment system modification: a case study in Réunion

Tests were conducted at the Sezela sugar mill in South Africa and in Réunion (Lejars, 2006; Papaiconomou, 2004)[3]. Here we discuss the case study in Réunion.

We analysed the effects of changing a payment system on growers' income, under three different supply methods, for the 3 278 sugarcane growers listed in the database of the Centre interprofessionnel de la canne et du sucre (CTICS). The effects of switching from an absolute payment system (growers are paid according to the real weekly sugar content) to a relative payment system were simulated (Figure 2). The analysis showed that this change in payment system did not modify the sharing of sugar profits between commercial stakeholders and growers. For growers, the relative payment system was less restrictive in terms of supply dates and frequencies, i.e. cane can be delivered less regularly, at any period during the milling season, without modifying their income. This payment strategy thus facilitates mechanized harvesting organization and the formation of growers' groups. Finally, the relative payment system enables fairer sharing of the added value between growers within the framework of quota reallocation that takes supply batch quality into account.

2 Lejars C., 2005. Evaluation des systèmes de paiement de la canne à sucre dans quelques pays producteurs. Impact du mode de paiement sur la qualité des cannes et sur l'organisation des approvisionnements dans quelques industries sélectionnées. Département des Cultures annuelles du CIRAD, UPR 5 Systèmes canniers, CIRAD, Montpellier, France, 53 p.

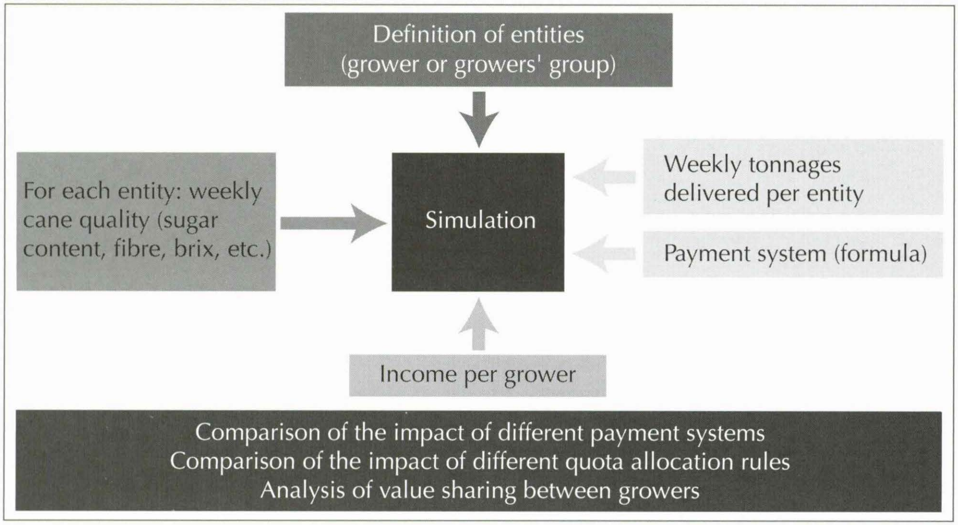


Figure 1. Tool for simulating impacts of payment and organization methods on growers' income.

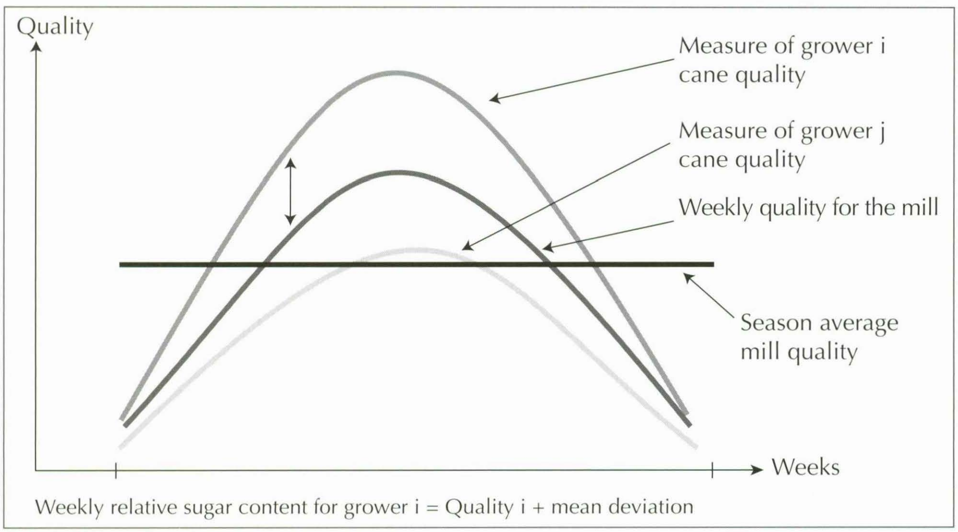


Figure 2. Definition of absolute and relative sugar content.

Lejars C., 2006. Qualité des approvisionnements et systèmes de rémunération des agriculteurs. Cas de la filière canne à sucre à La Réunion. Département des Cultures annuelles du CIRAD, Unité de recherche 5 (Systèmes canniers), CIRAD, Montpellier, France, 57 p.
Papaiconomou H., 2004. Evaluation de différents systèmes de paiement dans le cadre d'une réorganisation des approvisionnements d'une sucrerie : application d'une démarche de simulation au bassin de Sezela, Afrique du Sud. DAA thesis, INA-PG, France, 50 p. + appendices.

3

MAGI—to enhance sugar mill supplies

S. Auzoux
UPR 13 Decision Support and Biostatistics
C. Lejars
UPR 5 Sugarcane Farming Systems
P.-Y. Le Gal
URP 43 Innovation and Dynamics of Farming Systems

The MAGI software package is used to simulate cane supply organization scenarios on a sugar mill area scale. This tool provides support for decision making and negotiations between growers and commercial stakeholders. It has been disseminated in South Africa, Mauritius and Réunion. MAGI was developed by CIRAD, in partnership with the French Institut national de la recherche agronomique (INRA) and the South African Sugarcane Research Institute (SASRI). It was programmed in Visual Basic.Net with an Access® database structure and can be accessed online free of charge at: http://agri-logistique.cirad.fr.

→ Cane supply improvement strategies

Improving sugar mill supply management is a key to increasing the efficiency and cost-effectiveness of sugarcane sectors. In this industry, as in most others, a steady supply of raw materials is required for processing. Cane flows should be organized such that the processing capacity of the mill is saturated, thus avoiding potential losses (flow interruptions, expense sources, overstocks, etc.). Moreover, for agricultural raw materials that cannot be stored, the mill operating time is directly linked with the harvesting periods. It is thus essential to plan and manage supplies by taking both industrial and agricultural constraints (raw material maturity, harvesting area and hauling equipment performance, etc.) into account.

Many problems may arise when attempting to reconcile agricultural supply and industrial demand due to uncertainties and structural constraints weighing on the supply function. The practical problem is to first determine flow planning and management methods geared towards saturating the industrial capacity and, secondly, the structuring of supply areas so as to be able to efficiently respond to production or demand variability and, from a logistic perspective, to ensure rapid delivery to sugar mills.

The approach involves looking for organization methods that could increase sugar production and finding trade-off solutions based on a shared representation of the functioning of the sugar mill area, while integrating each stakeholder's constraints and objectives. The target objectives are:
– to reduce harvest organization, haulage and mill cane reception costs, which represent up to 70% of total production costs

– adjusting harvesting durations and dates so as to achieve maximum cane sucrose contents, thus optimising the quantity of sugar produced in sugar mill areas
– reconciling the constraints and objectives of all stakeholders.

A sugar mill supply planning and management model was thus designed to simulate different supply reorganization scenarios. This model provides discussion support for stakeholders in the sector. This led to the development of MAGI, as specific application tool for modelling and simulation of supplies in sugar mill areas.

→ Supply modelling and simulation

MAGI can illustrate the mill supply process on a weekly basis throughout a milling season. It combines three modules (Figure 1):

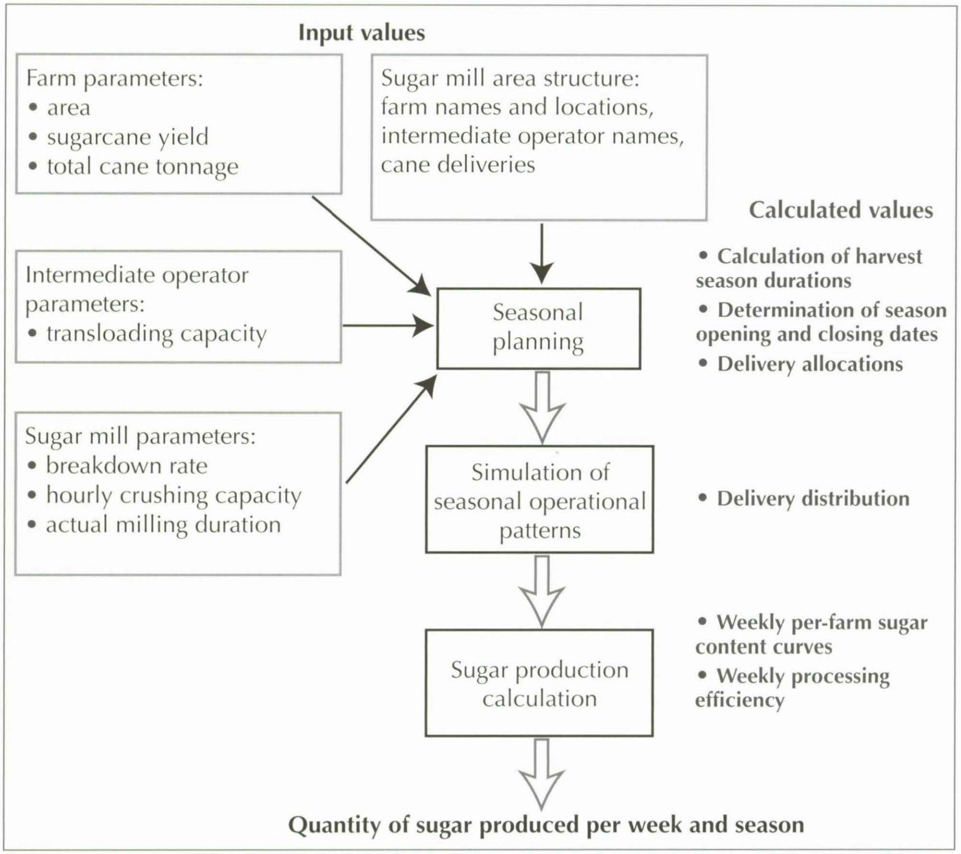


Figure 1. The three supply modelling components in MAGI.

– a planning module to draw up weekly cane delivery schedules from sugarcane farms to intermediate operators and then the mill
– a simulation module to calculate season durations and implement the plans
– a processing module to assess the weekly quantity of sugar produced on the basis of the results of the two previous modules.
The simulation is a four-step process. First, the structure of the mill supply area is determined, i.e. the area is divided into production units, and cane flow pathways from these units to the mill are also defined. Secondly, the season durations and opening and closing dates are calculated on the basis of the mill crushing capacity and the total predicted cane tonnage delivered. The third step simulates seasonal operational scenarios for each production unit according to a predefined supply schedule. Finally, the quantity of sugar produced is calculated from weekly sugar content curves, weekly losses and the mean mill crushing capacity. The different scenarios are compared according to the sugar gains achieved.

→ Practical applications

MAGI can be used for several types of simulation. Variations in the model input values can be tested to compare their effects on produced sugar quantities. For instance, the mill crushing capacity or mill supply area structure (number of intermediate operators, number of transloading platforms) Similarly, it is possible to assess sugar gains induced by changing cropping plans for sugarcane varieties, i.e. planting several early or late varieties that will achieve maximum sugar contents at different periods.

A more dynamic aspect involves modifying planning rules so as to make effective use of sugar content differences within mill supply areas: determining how to adjust the season to be centred on peak sugar content periods, adjusting delivery allocations according to local sugar content variability patterns, etc. It is also possible to assess whether resized equipment would be necessary for each new delivery allocation.

→ Prospects for MAGI

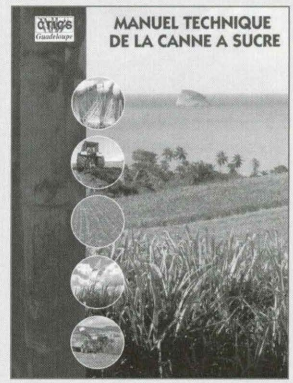
Discussions are under way on implementing MAGI in other countries such as Brazil or Australia. It could also be interesting to tailor it to other crops, such as cotton or oil crops, that have a supply system similar to that of sugarcane. A thesis study is currently under way on developing a statistical cane sugar content prediction model. This model could be integrated in MAGI to enhance delivery allocation for growers and to better adjust delivery schedules according to peak sugar content periods.

Publication of agricultural handbooks

Sugarcane cropping manual

Centre technique interprofessionnel de la canne et du sucre de la Guadeloupe
2005, 94 p.
To get a copy of this manual (currently only available in French), contact:
Centre technique interprofessionnel de la canne et du sucre (CTICS), Morne l'Epingle - Providence, BP 225, 97139 Les Abymes cedex, Guadeloupe, France

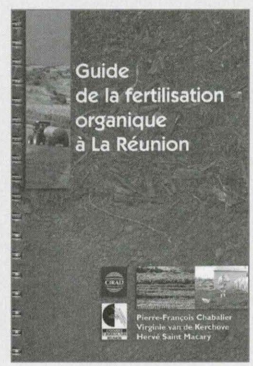
The *Manuel technique de la canne à sucre* (sugarcane cropping manual) reviews knowledge on sugarcane cropping in Guadeloupe. This manual is an educational tool designed to boost public awareness on this topic. CTICS coordinated a team of specialists from CIRAD and other partner organizations to draw up this reference manual, which integrates new research findings and professional experience. Global economic aspects of sugarcane are briefly covered, and the focus is specifically on outlets in the West Indies. Sugarcane morphology, physiology and plant cycles are explained and fully illustrated. The chapters on cropping techniques (planting, fertilisation, crop protection, irrigation) are practical and refer to the soil and climate conditions in Guadeloupe. The part on harvests, payment and cane sugar content provides a detailed account of all steps: harvesting, transport, mill measurements and reception, as well as payment conditions. This manual covers applications in Guadeloupe but should also interest professional operators of other sugar cane-producing regions and novices from different backgrounds.



Handbook on organic fertilization in Réunion

Pierre-François Chabalier, Virginie Van de Kerchove, Hervé Saint Macary
CIRAD, Chambre d'agriculture de La Réunion
2006, 302 p.
Contact: Pierre-François Chabalier, pierre.chabalier@cirad.fr
This handbook is available in electronic format (currently only available in French):
www.mvad-reunion.org/rubrique.php3?id_rubrique=53
To get a hardcopy version of this handbook, contact:
Mission valorisation agricole des déchets (MVAD)
Chambre d'agriculture
24 rue de la Source
BP 134, 97463 Saint-Denis Cedex, Réunion, France

The *Guide de la fertilisation organique à La Réunion* (handbook on organic fertilization in Réunion) reviews knowledge on organic matter produced in Réunion and on practical aspects of regulations and the use of this material for agricultural applications. This handbook should assist producers of organic matter and waste (farmers, municipalities, agrifood industries) with respect to supplying organic matter that can be utilised, and also help users on rational organic matter fertilization procedures. It includes a first nine chapter general section on cropping, the soil, analyses, organic matter use, risks, regulations and application procedures. The second section presents technical data on fertilization calculations, crops, field sampling and 26 different types of organic matter.



This handbook provides answers to many questions concerning the use and recycling of waste and organic matter in agriculture on the basis of technical references and regulations in temperate areas such as metropolitan France or, on a larger scale, Europe, and on knowledge acquired in the tropical environment of Réunion. This handbook could thus interest users in metropolitan France and other tropical areas. It targets all stakeholders in the agricultural community: chambers of agriculture, cooperatives, technicians and farmers, communities, teachers, scientists, engineering offices, etc.

Technical and economic data repository for sugarcane farms in Réunion

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In 2005, at the request of the Direction de l'agriculture et de la forêt (DAF), CIRAD developed a technical and economic data repository for sugarcane farms in Réunion. Within the framework of reforms of the Common Organisation of the Market in Sugar, this repository served as a reference database and tool for determining compensatory public aid in 2006.

The main aims were to:
– create a tool for archival storage and monitoring of production cost patterns and margins in the sugarcane sector
– identify the most representative cropping systems in Réunion and pinpoint their features (crop management sequences, operational methods, locations) and assess the economic results (costs, sales figures, income, productivity)
– develop a simulation tool to measure the sensitivity of farm results to economic fluctuations, such as increases in input prices, decreases in sugarcane tonnage prices and variations in subsidies allocated to growers.
This study was conducted in collaboration with the Chamber of Agriculture in Réunion and partners in the sugarcane sector—Comité de pilotage de la canne, Sucrière de La Réunion, Bois Rouge, CIRAD, DAF, CNASEA, CTICS, CERF and Conseil général.

First, a synopsis of data from current regularly updated farm databases was drawn up. Then a type classification of sugarcane farms representative of cropping systems in Réunion was done. The method involved comparing physical environmental variability criteria and farm structure criteria on the island. Schematically, only a few major differentiation criteria were used to determine typical cropping systems (Table 1). Then, for each cropping system, an average crop management sequence was determined. A major data collection and expert assessment helped to quantify the technical and economic features of each crop management sequence (Table 2).

→ Eighteen sugarcane cropping systems

Eighteen cropping systems, accounting for 84% of the sugarcane-growing area, were classified (Table 3). Eleven systems were found to be most representative of the real situation in terms of cropping area. Seven systems were not very representative, but they were selected because they could be developed in the near future (Table 3: shaded areas). Each system was characterized by a crop management sequence and a set of criteria that were dependent on the environment and the equipment (examples in Table 4). All of these characteristics were considered to calculate the annual agricultural income of reference farms, along with their expenses and gross income structure.

Table 1.

Criteria for characterizing and quantifying sugarcane cropping systems in Réunion: environmental variability criteria and farm variability criteria.

Criteria	Detailed description of criteria
Climate: 5 zones	Humid rainfed zone Dry western rainfed zone Dry northern rainfed zone Spray irrigated zone Drip irrigation zone
Elevation: 2 zones	'Lowland' zone, encompassing the following layers: 0-200 m in humid rainfed zone; 0-600 m in dry rainfed zone; 0-400 m in irrigated zone 'Highland' zones: > 200 m in eastern zone (humid rainfed); > 600 m in western zone (dry rainfed); > 400 m in western irrigated zone
Mechanisation capability: 5 zones	This combines 3 criteria (slope, stoniness, plot geometry) to give 5 capability zones: Zone A1 (slope < 10% and nil stoniness): no development required, whole-stalk harvesting possible Zone A1-a (10-20% slope and nil stoniness): whole-stalk harvesting possible Zone A2: minor to medium development Zone A3: major development required, with manual harvesting Zone A4: mechanization impossible, manual harvesting
Internal equipment and farm size	Unequipped: < 650 t of cane (utility vehicle only); < 12 ha Equipped: > 650 t (at least one tractor); 12-20 ha

Table 2.

Technical and economic criteria considered in the type classification of sugarcane farms in Réunion.

Criteria	Explanations
Cane yield	Evaluated according to expert advice for each cropping system
Cane sugar content	4 values, according to CTICS 1996-2004 data
Family labour	Total labour (family and external) is defined in a work time matrix for each system
Cropping cycle	12-18 months according to the zone and crop age. 5, 7 or 10 year replanting cycle, depending on the cropping system
Land improvement and tillage	Large and small stone removal; pest and disease control treatment; tillage labour time; road maintenance costs
Irrigation installation and maintenance	Spray; drip; water needs; water prices
Planting and replanting	Replanting support; inputs; labour time
Input supplies and maintenance	Fertilizers; herbicide applications, prices and formulation; labour time
Structural and operational expenses	Financial depreciation and costs; social contributions; insurances; average farm rent
Harvesting, loading, hauling	Mechanized systems: internal loading and hauling. Farm equipment costs Unequipped systems: service providers
Mechanization	Hypothesis: Hypothesis: farms mechanically equipped when the Comité technique à la mécanisation provides a 25% subsidy wit a ceiling of €7 700 (farms producing over 650-700 t) Machinery: tractor, loader, trailer, sprayer Number of hours, consumption and maintenance calculated

Equipped cropping systems

Climate	Elevation	Zone with a mechanization capacity (classified in Table 1)	Harvesting	Total area in Réunion (ha)
Humid rainfed	Lowland zone	A1 – A1-a	mechanical	1 655
		A3	manual	2 130
		A4	manual	570
	Highland zone	A1 – A1-a	mechanical	915
Irrigated	Lowland zone	A1 – A1-a	mechanical	610
		A3	manual	760
Dry rainfed	Highland zone	A1 – A1-a	manual	190
Total equipped systems				7 077 (28.3% of the total area under cane)

Unequipped cropping systems

Climate	Elevation	Zone with a mechanization capacity (classified in Table 1)	Total area in Réunion (ha)
Humid rainfed	Lowland zone	A3	2 250
	Highland zone	A1 – A1-a	1 165
		A3	1 186
		A4	670
Dry rainfed	Lowland zone	A1 – A1-a	1 630
		A3	2 270
	Highland zone	A1 – A1-a	1 160
Irrigated	Lowland zone	A1 – A1-a, A2	1 645
		A3	1 400
	Highland zone	A1-a	180
Total unequipped systems			14 056 (56.0% of the total area under cane)

Table 3.

The 18 reference cropping systems (in shaded areas, 7 systems that could be developed in the near future).

Table 4.

Example of two of the most representative cropping systems (equipped and unequipped).

Differentiation criteria	Most representative equipped system	Most representative unequipped system
Climate and elevation	Humid rainfed; lowland zone	Dry rainfed; lowland zone
Area (ha)	12	5
Yield (t/ha)	90	50
Total tonnage at harvest (t)	1 080	250
Zone with a mechanization capacity	Harsh zone A3	Harsh zone A3
Harvesting and equipment	Manual harvesting 90 CV tractor, boom sprayer, loader, skip, light truck	Manual harvesting Utility vehicle
Land improvement	Large stone removal, heavy disk ploughing	Large stone removal, heavy disk ploughing
Planting	Manual (furrow plough)	Manual (furrow plough)
Fertilization	Manual application	Manual application
Herbicide	1 boom spray (pre-emergence) and one lance spray (late treatment)	2 manual sprays (post-emergence) and late treatment on 40% of the area
Total area in Réunion (ha)	2 130	2 250

→ Two new software tools

Two new software tools were developed at the end of this study. The first '2005 data repository' tool is a database containing all production costs and labour times associated with sugarcane cropping activities. It is used for data archival storage and updating. The '2005 data repository' will be updated annually, in addition to archival storage of production cost data. This tool will be further developed with a more user-friendly support than Excel®.

The second simulation tool explains sugarcane cropping expenses and margins on the basis of a budgetary calculation. It analyses the income structure of cropping systems determined in the repository. It can be used to analyse the effects of sugarcane price variations, or changes in national and EU subsidies (reformulation and integration of new subsidies) on a farm scale and, by aggregation, on an island scale. This simulation tool was handed over to DAF in 2006 to help this directorate to set up new subsidies implemented under the 2006-2014 Cane Convention.

Remote sensing to enhance sugarcane yield forecasting and crop field monitoring

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Remote sensing research under way on sugarcane is aimed at developing automatic satellite image interpretation tools and sugarcane-cropping area management tools. The information needs of the sugarcane sector in Réunion were taken into account to design relevant crop field monitoring tools.

Since 2002, in compliance with the Common Agricultural Policy, information on sugarcane cropping areas in Réunion is collected yearly through surveys of growers. The results of these surveys are centralised by the Direction de l'agriculture et de la forêt (DAF, agriculture and forest authorities). The parcel plan is then digitized on a farm block scale from Institut géographique national (IGN) orthophotographs, which are updated on a 5-year basis. This parcel plan, which includes a broad range of information (growers, delivery centres, irrigation methods, etc.), represents an important database for management of the sugarcane sector.

These surveys do not, however, provide information on changes in the status of individual plots during the crop growth cycle, even at harvest. During the harvesting period, sugarcane yield and sugar content are measured at cane delivery, but these measurements are attached to the grower's name, not to the harvested plot. However, with satellite imaging, changes in the sugarcane-cropping area can be monitored plot by plot throughout the cropping season until harvest through analyses of sugarcane area spectral responses, vegetation index calculations, computer-assisted photointerpretation, etc. Our research in this field is based on SPOT 4 and SPOT 5 satellite image processing and correlations with field data.

→ Partnerships

This research has been conducted since 2002 by CIRAD's team at the Maison de la Télédétection (remote sensing centre) in Montpellier and CIRAD's sugarcane research centre in Réunion. The results were the focus of a PhD thesis funded by the Réunion Région (E. Bappel, 2005[1]) within the framework of the SUCRETTE project (remote sensing sugarcane monitoring project funded by the Terre et Espace network), in partnership with the SPOT Image group, which manages the technical and commercial promotion of the developed products, and the Mauritius Sugar Industry Research Institute (MSIRI), which was involved in determining the needs and testing the products. In Réunion, sugar industry stakeholders—mills, Chamber of

1 Bappel E., 2005. Apport de la télédétection aérospatiale pour l'aide à la gestion de la sole cannière réunionnaise. PhD thesis on Signal and image processing. Université de La Réunion, Saint-Denis; CIRAD UPR 5 Sugarcane Farming Systems, Saint-Denis, Réunion. CIRAD, Montpellier, France, 278 p.

PhD thesis: Application of remote sensing to enhance management of the sugarcane-cropping area in Réunion

The PhD thesis of E. Bappel (2005) focused on investigating the potential of aerospatial remote sensing to enhance management of the sugarcane-cropping area in Réunion. SPOT 4 and SPOT 5 images captured in 2002 and 2003 were used. CASI (Compact Airborn Spectrographic Imager) hyperspectral images were acquired in September 2002. Simultaneously, biophysical parameters describing the state of the sugarcane cover (leaf area, nitrogen levels, crop biomass) and agronomic parameters (monitoring of harvests and replanting) were monitored by a field measurement procedure.
The leaf area index (LAI) and sugarcane yield were estimated on the basis of NDVI indices. With SPOT data, the best estimate of sugarcane yield on a plot scale was achieved by combining the MOSICAS sugarcane growth model and leaf area patterns determined on the basis of SPOT 4 and 5 images. The CASI hyperspectral data provided a better estimate of the leaf area and green biomass levels as compared to SPOT 4 and 5 data. The CASI data also enabled an estimate of leaf nitrogen levels, i.e. a sugar content indicator during the ripening stage.
The possibility of differentiating sugarcane plots according to their surface conditions (full vegetation, harvested or tilled) enabled the development of dynamic operational mapping operations for the sugarcane cropping area in almost real time (monitoring of harvests and replanting).

Agriculture, Centre technique interprofessionnel de la canne et du sucre (CTICS), DAF, steering committee, SICA Sud Canne, etc.—were consulted and provided assistance.

Finally, CNES *Information satellitaire pour l'environnement de La Réunion* (BD-ISLE-Réunion) provided access to their SPOT image bank, which has been developed for research purposes.

→ Preliminary results: digitization of agricultural parcel plans

Some products developed in the SUCRETTE project could only be implemented if the parcel plan is partitioned on a crop plot scale (plot defined by a single crop management sequence). This is the case for inter- and intra-plot variability maps, but also for remote sensing yield forecasting maps. For harvest monitoring, this partitioning has two advantages:
– increasing the reliability of image processing results obtained on a sugarcane plot scale, not a farm block scale (the block includes, in addition to sugarcane fields, windrows, trails and sometimes infrastructures that can alter the signal measured by remote sensing);
– improving the cartographic representation by creating a parcel layer with a status as attribute (harvest, nonharvest, during harvest) while setting the harvesting progress rate thresholds attributed to each plot at the end of processing.

A parcel plan partitioned on an elementary plot scale (plot whose edges are visible at the digitization image resolution) was thus digitized by CIRAD on the basis of DAF 2004 parcel blocks and IGN 2003 orthophotos (resolution 0.5 m). The above-mentioned products could be developed since the elementary plots are under specific crop management sequences. The parcel plan was updated in 2006 by photointerpretation on the basis of DAF 2005 surveys and a SPOT 5 image (resolution 2.5 m) acquired prior to the 2006 harvest.

→ Harvest forecasting

Several harvest forecasting methods use remote sensing data. The method we used is based on the indirect relationship between the normalized difference vegetation index (NDVI[2]) of a plant cover and the green biomass of this cover. This relationship was determined from a set of data obtained experimentally on a plot scale in Réunion and Guadeloupe, and from SPOT images in 2002, 2003 and 2004. Cane yield could be estimated by using a maximum NDVI with a root mean square error (RMSE) of 13.65 t/ha. As this vegetation index is maximal just prior to the beginning of harvest, the yield can thus be estimated by remote sensing on the basis of a satellite image acquired in the month preceding sugarcane harvest onset.

2 Normalized difference vegetation index: vegetation index based on the chlorophyll activity calculated on the basis of red and near-infrared spectra on satellite images. NDVI = (PIR – R) / (PIR + R)

This relationship was applied to each individual plot on an island-wide scale in Réunion during the 2004 and 2005 crop seasons (Table 1). The results were obtained by processing two SPOT images acquired on 13 May 2004 and 06 June 2005, on which plots with bare soils or vegetative growth that was too low for harvesting were masked. The remote sensing based yield forecasts overestimated the harvest (Table 1). This overestimation could be explained by four factors:
– the relationship between NDVI and yield was calibrated on rainfed high-yielding plots and may be incorrect under irrigated conditions
– the 2003 plot plan was used, whereas the DAF survey showed that the sugarcane area had decreased by 400 ha in 2005 (– 1.5%, etc.)
– for the 2005 season, when the error was higher, the climatic conditions were poor during harvesting (irregular and delayed rainfall, low sunlight)
– the geometric and atmospheric conditions during SPOT image acquisition. The NDVI, even though it is not very sensitive to atmospheric conditions, can vary according to the geometric conditions of image acquisition.

For harvest forecasts, the relationship between NDVI and yield will be improved by separating irrigated areas and identifying plantations and ratoons. Moreover, CTICS collects samples on check plots for harvest forecasting purposes—the satellite image data obtained before harvesting will be compared with the CTICS yield predictions for the same plots.

→ Harvest monitoring

Cane cutting progress results during the harvest period were obtained by processing a SPOT 5 image acquired on 6 June 2005 to identify bare soils (unplanted) before the harvest season, and processing a SPOT 4 image acquired on 5 August 2005 to monitor harvesting (Figure 1). These treatments mainly involved unsupervised classifications and grouping classes by photointerpretation and expertise.

Following digitization of the sugarcane parcel plan on an elementary plot scale, it is now possible to introduce new plot attributes corresponding to cutting progress for each elementary plot. The decision to subsequently classify a partially harvested plot as 'harvested' or 'unharvested' depends on the threshold harvest rate values, which were set at 25% and 50% in this preliminary study. A more indepth study is now required on the effect of the threshold value on the cutting progress statistics.

Year	Remote sensing forecast (canne, million t)	Actual yields (canne, million t)	Error (%): (estimated tonnage - actual tonnage) / actual tonnage
2004	2.099	1.969	6.6
2005	1.999	1.801	11.0

Table 1.
Comparison of remote sensing cane production forecasts and actual yields obtained in 2004 and 2005.

After image acquisition, it takes about a week to obtain harvest monitoring results. Assuming that a plot in which harvesting has begun will be entirely harvested within a week, it is possible to predict the supplementary quantity that will be delivered in the week following image acquisition. These forecasts closely match the actual seasonal yields at the time when the results are delivered.

Figure 1. A map showing the mapping results concerning harvesting progress on sugarcane plots in northwestern Réunion on 5 August 2005.

→ Mapping inter-plot heterogeneity

The aim of mapping inter-plot heterogeneity is to assess variability in sugarcane plot surface states by calculating indicators to simplify spectral and spatial information contained in a satellite image: vegetative growth indicator (mean chlorophyll activity level) and crop heterogeneity indicator.

These maps are produced during the months preceding the harvest period when all ratoons are comparable in terms of vegetative growth. Mapping of vegetative growth, based on the mean NDVI per plot provides access to the spatial distribution of the potential of plots in a cropping area. Similarly, calculating the NDVI variation coefficient (ratio between the standard deviation (SD) and the mean NDVI per plot) on a per-plot scale provides information on the plot heterogeneity level. This type of map helps stakeholders locate plots in which there are sugarcane growth problems.

In Réunion, these maps can help in selecting plots sampled by CTICS for harvest forecasting (Figure 2). They can also be useful for subsequently validating plot choices by ranking them within per-plot NDVI distributions in a sugarcane-growing area.

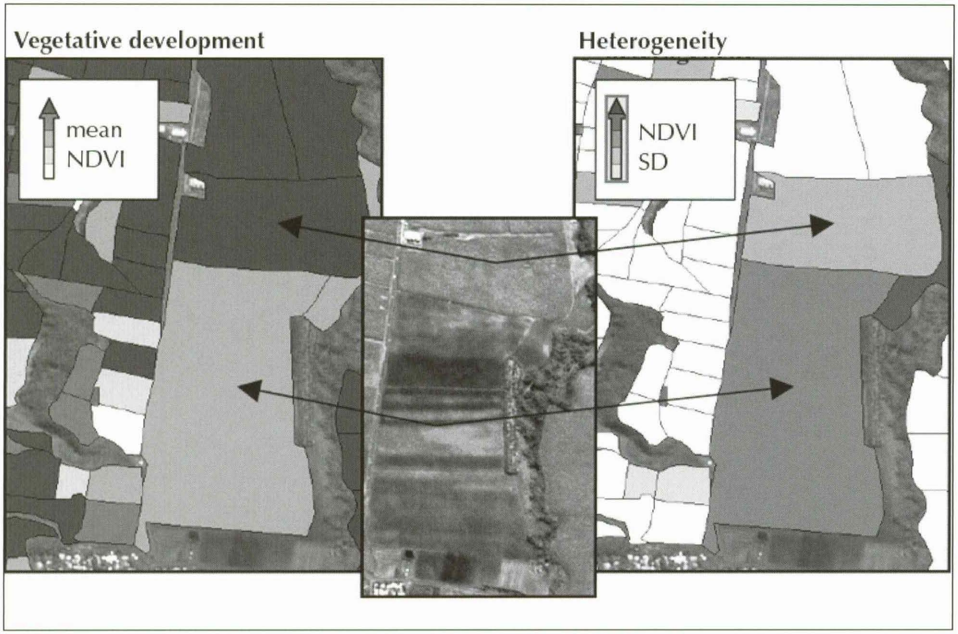

Figure 2. A map showing vegetative development and plot heterogeneity on a SPOT 5 image acquired on 6 June 2005.

→ Prospects: from satellite imaging to drone imaging

Satellite imaging provides a unique way to obtain information on an entire sugarcane growing area in almost real time. However, on a plot scale, satellite imaging can be limited by the spatial resolution. Moreover, the spectral range of current probes does not enable an indepth analysis of the status of a crop. To overcome these problems the AgriDrone project of CIRAD (UPR 5 Sugarcane Farming Systems and UMR TETIS) and CEMAGREF plan to use onboard probes on drones and ULMs to assess the water and nutrient status of sugarcane crops. A PhD thesis, funded by the Réunion Région, is associated with this project, which is funded by the French Ministry of Agriculture and Fisheries.

Training: remote sensing assisted production management

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From September 2002 to December 2004, CIRAD and the Spot Image group pooled their expertise to lay the technical and economic foundations for developing a tool to enhance management of the sugarcane sector (SUCRETTE project: remote sensing sugarcane monitoring). Funded by the Terre et Espace network for research and technological innovation of the French Research Ministry, this project has been conducted at three pilot sites in Guadeloupe, Réunion and Mauritius. The Spot Image group, a project partner, manages the technical and commercial promotion of the developed products.

The SUCRETTE project has thus given rise to a service proposal, i.e. *Aide à la gestion de production* (production management assistance) of the Spot Image group (www.spotimage.fr/html/_55_138_791_.php), in which CIRAD is responsible for knowledge and technology transfer. Within this framework, a training session has been organized on the remote sensing sugarcane production management approach and associated software tools used. This training targets stakeholders in two fields:
– public remote sensing operators (service companies or institutional entities using GIS and image processing) who develop cartographic products derived from satellite images
– public dissemination agencies (e.g. institutional bodies, manufacturers, operating managers) responsible for customizing and disseminating information (statistics, maps, reports).

This training is focused on four thematic products: parcel plan creation and updating, harvesting and tillage monitoring, and inter- and intra-plot variability. Trainees are also instructed on using the associated software: field plot data entry and updating tools, cartographic and statistical product dissemination tools.

The Spot Image group and CIRAD, through their international networks and participation in technical seminars, are promoting this remote sensing approach to sugarcane production.

Sugarcane in Réunion—a key to sustainable development

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Following the seminar *L'avenir de la recherche sur la canne à sucre : Quelles recherches prioritaires à l'horizon 2007-2013 ?* (The future of sugarcane research: What are the research priorities for the 2007-2013 period?) held in Saint-Denis, Réunion, 20-24 September 2004, the industry would like CIRAD to study the environmental implications of sugarcane cropping in Réunion. This bibliographic review (Courteau, 2005)[1] highlights the environmental advantages of growing sugarcane under Réunion conditions. All of the arguments were also presented to European Commissioners during their visit to Réunion, just prior to discussions on the Sugar Agreement of the Common Market Organization for Sugar.

The sugarcane industry in Réunion has a direct impact on the lives of local inhabitants. This is the only export market oriented industry, accounting for two-thirds of total exports of Réunion. 15 000 people are employed in this industry, with sugarcane bringing in 30% of farmers' income. Intermediate products and services are also involved (fertilizers, transportation, harvesting and land development work, etc.). Moreover, through its multifunctionality, it has a role in territorial development, and contributes to the landscape quality and attractiveness for tourism. In addition to these social and economic functions, sugarcane cropping has many environmental advantages (Table 1), three of which are strategic:

- this crop is efficient in controlling erosion on this steep sloped island with a cyclonic climate
- it promotes energy self-sufficiency. The use of bagasse for energy currently accounts for a quarter of the electricity produced on the island
- it facilitates livestock waste recycling. As waste management is becoming increasingly problematic, especially on islands, applying this waste as a fertilizer in sugarcane fields is a prime way to recycle this material.

This study is a first step which involves compiling current scientific references on this topic. It should give rise to relevant topics for future research, e.g. studies on the carbon cycle, analysis of the sugarcane crop cycle, studies on developing sugarcane byproducts and promoting awareness on the non-market functions, especially environmental of sugarcane cropping. These themes require special attention and complementary research strategies.

1 Courteau A., 2005. La canne à sucre et l'environnement à La Réunion : revue bibliographique. Université de Franche-Comté, Besançon, CIRAD, La Réunion. CIRAD, Saint-Denis, La Réunion, France, 53 p. [Online] [16 June 2006] URL: www.cirad.fr/reunion/recherche/canne a_sucre Section *En savoir plus*.

Table 1.

Environmental advantages of sugarcane in Réunion

Environmental advantages	Brief explanation
Sugarcane crops are efficient for erosion control	Deep dense rooting Resistance of above-ground organs to harsh conditions such as hurricanes Permanent soil cover by the very dense vegetative organs and green harvesting with the crop residue left in the field Bare soils very uncommon and dispersed in the landscape
Agricultural practices enhance soil properties	Preservation of organic matter by roots and crop residue Mineral inputs via their decomposition Maintenance of high biodiversity in the soil Fertilizer inputs increasingly calculated to meet needs Pest and disease control using very few chemical products (breeding and biological control are promoted)
Growers and the industry are striving to use less water	To achieve a cane yield of 60-120 t/ha, the crop consumes 270-330 l of water per kg of sugarcane dry matter; maize requires twice this amount Sugarcane promotes groundwater conservation by facilitating water infiltration via its dense bushy root system. Industrial stakeholders have decreased their water consumption by twofold over the last 10 years (Sucrière de La Réunion: ratio 1.15 m^3 of water per tonne of milled cane in 2004) These stakeholders are also striving to reduce the water consumption ratio per produced energy unit
Greenhouse gas: a positive carbon balance	Sugarcane crops represent a carbon sink due to green harvests A comparison of bagasse and coal power units is by far in favour of bagasse CO_2 emissions since bagasse combustion does not add to that already contained in the biosphere because photosynthesis in growing plants offsets these emissions
Sugarcane byproducts are being developed	An original subsector that could serve as an example Bagasse: renewable energy source Filter mud: organic agricultural amendment Stillage: field application testing under way (studies on new products)
The sugarcane industry complements other agricultural sectors	Recycling of livestock production effluents Food supply for livestock Carbon support for compost Mulch source

Sudan: effects of applying sugarcane-mill filter mud on plantation soils

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The effects of sugarcane-mill filter mud on soil microbiological activities and on sugarcane yield are currently being studied as part of Thabit Elsayed's PhD thesis research carried out jointly at the Kenana Sugar Company (KSC, Sudan) and in CIRAD's laboratories in Montpellier, France. The results should give rise to efficient methods for utilising filter mud, with the dual aim of reducing chemical fertilizer use and eliminating smoke generated by spontaneous combustion of filter mud in waste dumps.

Tests were first conducted to certify that filter mud is not detrimental to small-seeded plants or sugarcane germination. Then a curve was plotted concerning the response of cane crops to filter mud applications in the presence of nitrogen fertiliser, with the aim of avoiding the problem of nitrogen starvation due to the input of carbon compounds in the soil.

Controlled incubations were carried out in CIRAD's laboratories in Montpellier using soil-sugarcane-mill filter mud mixtures. The impact of filter mud was measured on specific activities of certain enzymes from soilborne organisms.

The promising initial results prompted further studies which were conducted at the KSC site in Sudan and in the Montpellier laboratories in 2006.

The impact of high-volume filter mud applications on the quality of vertisols in the KSC experimental fields and on sugarcane crops (yield, sugar quality) will now be studied. Large-scale application techniques should also be tested.

Evaluation of global bagasse production—energy potential

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The European ULCOS (Ultra Low CO_2 Steelmaking) project aims to come up with effective technical solutions that would decrease greenhouse gas emissions by at least 50% in the steelmaking process. This project is funded within the framework of the 6^{th} Framework Programme for Research and Technical Development (6^{th} FPRTD) of the European Union. A consortium of 48 partners (steelmakers, including Arcelor, steelmaking suppliers, electricity and energy producers, including EDF and Air Liquide, public and private research institutes, European universities, etc.) was formed to carry out this project.

The use of renewable biomass, especially agricultural or agroindustrial residue as a substitute for coke is one of the solutions being studied. The sugarcane industry is interested since research has been under way in recent years to come up with sugarcane byproducts other than sugar to develop. In several countries, some byproducts are already enhancing the cost-effectiveness of sugarcane, e.g. ethanol in Brazil, pulp in Indian and China, electricity in many other regions. Moreover, the use of sugarcane biomass as an energy source is being discussed to an increasing extent within the framework of the Common Market Organization for Sugar.

The CIRAD study focused on assessing global available bagasse supplies to be used as fuel (in charcoal form) in blast furnaces. However, 80% of all bagasse is used as an energy supply in sugar mills and many sugar-producing countries already use all of their bagasse for cogeneration, ethanol synthesis, pulp, etc. Global bagasse production over and above these uses was thus inventoried.

Despite the high global production, only 6 million t of bagasse could be processed into 1.3 million t of charcoal. This low supply is located in highly dispersed sugarcane-growing areas, so transportation costs are high. However, countries that are already utilizing all of the sugarcane biomass produced nationally could represent a very large stock (70 million t of total biomass in Brazil), but these resources are being utilized in competitive sectors (ethanol ad electricity production). Part of this stock could likely be recovered but this would have to be the focus of financial and political negotiations. Finally, for least advanced countries, processing bagasse into charcoal briquettes is of sufficient interest to warrant international aid from an environmental conservation (reducing CO_2 emissions and deforestation) and economic (onsite charcoal briquette production) perspective. In conclusion, considering the low volume of bagasse that could actually be recovered and transportation problems associated with the fact that production sites are scattered, bagasse is not a feasible fuel source for the European steelmaking industry.

Racin'situ training—field studies on root systems

J.-L. Chopart
UPR 5 Sugarcane Farming Systems
C. Jourdan
UPR 80 Functioning and Management of Tree-based Planted Ecosystems

CIRAD Racin'situ training sessions were held at the Centre d'étude régional pour l'amélioration de l'adaptation à la sécheresse (CERAAS) in Senegal in 2004 and 2005. Two senior scientists, i.e. J.-L. Chopart and C. Jourdan, trained around 30 participants from about 10 countries—students, scientists and technicians specialized in agronomy or ecophysiology—on studying root systems of annual and perennial crop plants in tropical environments.

Trainees are instructed on two original methods for analysing root systems in the field. On the basis of real cases, trainees learn data acquisition, input and analysis techniques using two software programs developed by CIRAD (Racine® and Rhizodigit®). They are instructed on using these programs for agronomic analyses (water management, fertilization, root dynamics and turnover, etc.).

Each session lasts 5 days. Two-thirds of the training time is devoted to supervised work in the field (setting up the root monitoring system and data acquisition) and on the computer (data analysis). The remaining time is devoted to theory (root functions, main methods for analysing root systems *in situ*) and information exchanges between participants.

In addition to the two software programs Racine® and Rhizodigit®, other tools used in the training include conventional tools (root sampling and measurement), the grid method (mapping root impacts, calculating root lengths, distances between roots and actual soil volumes available for the crop) and rhizotrons (monitoring root dynamics and turnover in a glass walled chamber).

Racin'situ training sessions will be held regularly in tropical regions. The next session is to be held in Réunion in 2006.

RAINETTE project— an agrometeorological network in Guadeloupe

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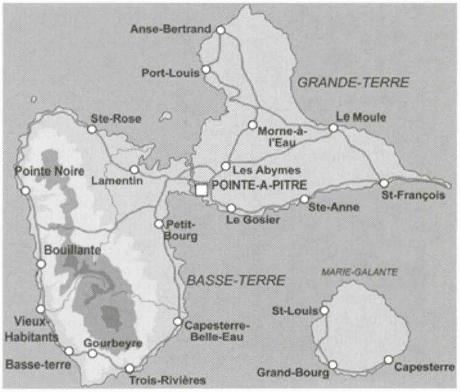
UPR 5 Sugarcane Farming Systems
J.-B. Laurent
UPR 13 Decision Support and Biostatistics

The RAINETTE project was launched in Guadeloupe in late 2004. It involves a network of 32 automatic agrometeorological stations that supply a database which is accessible to professional agricultural stakeholders at http://rainette.cirad.fr/index.php. This project is coordinated by CIRAD, in collaboration with many partners, including INRA, the Chamber of Agriculture of Guadeloupe, Sucrerie de Gardel SA, and Sociétés d'intérêt collectif agricole (SICA) in the sugarcane and banana sectors. It is funded by the European Agricultural Guidance and Guarantee Fund (EAGGF) and Guadeloupe Region.

This network of meteorological stations accounts for the climatic heterogeneity in agricultural production areas of Guadeloupe. These meteorological stations can be remotely queried and supply a database on a special server. CIRAD is responsible for data acquisition, control and uploading on the website.

This project finally provides access to meteorological data that is complete and reliable enough to serve as a basis for the development of crop management support tools. For sugarcane, it is now possible to develop more realistic and relevant MOSICAS (sugarcane growth simulation model) applications. It is also very useful as a support for advising agricultural sector training structures, for two reasons:
– it provides accurate information on climatic patterns for plant growth in different cropping areas and within the same area
– it provides updated information in almost real time and at low cost, thus enabling stakeholders to react immediately when weather conditions change.

The website http://rainette.cirad.fr/index.php is now highly visited and serves as a showcase to promote new partnerships on the basis of developed technologies.



Irrigation potential in northeastern Réunion

P. Langellier
UPR 5 Sugarcane Farming Systems

The future of the sugarcane industry in Réunion is currently at issue—the regular decline in the sugarcane cropping area, in addition to new provisions of the Common Market Organization for Sugar (reduction in European sugar prices aimed at reducing production). Intensification could safeguard this crop, which could be facilitated by the introduction of irrigation in many areas. Through the General Council of Réunion, the Sugarcane Steering Committee of Réunion relaunched an irrigation initiative for the Sainte Marie–Sainte Suzanne area in the northwestern part of the island. In this sugarcane-growing area, which is considered to be the most productive on the island, sugarcane cropping is steadily declining to the benefit of urban and road projects. Irrigation of this area would increase productivity, thus offsetting the loss of cropping area, while also demonstrating the benefits of irrigation in this region where growers wrongly consider that local rainfall is sufficient to cost-effectively manage crops. The General Council of Réunion accepted to fund this project and issued a call for tenders, and the Société grenobloise d'études et d'applications hydrauliques (SOGREAH) was selected. This company asked CIRAD to assess the irrigation needs and crop production potential in the target area.

In the sector studied, irrigation would enable a mean increase of 54 000 t of sugarcane as compared to the current production of 231 000 t with an annual irrigation flow rate of at least 15 million m^3 of water (volume calculated for a dry 5-year period). However, many sugarcane growers claim that they are ready for any agricultural diversification in response to changing market needs. Farmers seem truly interested in irrigation pending market price patterns and irrigation costs, which mainly depend on cubic-metre water prices at the terminal. The cost-effectiveness of irrigation also depends on plot locations. In addition to the technical aspects, following a socioeconomic survey, scenarios should be drawn up for areas that could actually be equipped for irrigation. SOGREAH is currently conducting feasibility studies.

Testing SMS messaging for irrigation management in Réunion

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R. Pirot
UPR 5

Only technicians currently have ready access to irrigation information that can be useful for developing guidelines for farmers and for decision making, which obviously limits the number of farmers who can receive timely advice. Most farmers, however, have a cell phone, which means that information could be transmitted via SMS messages. CIRAD's meteorological service at Ligne Paradis is thus now equipped with a GSM modem. Three systems are currently being tested prior to setting up a large-scale system.

The first test provides access to rainfall data from the meteorological network database managed by CIRAD. After registering with CIRAD's meteorological service at Ligne Paradis, users can request the latest rainfall data from a meteorological station by sending the French statistical INSEE code of the station (currently used by some agricultural technicians). Otherwise, if this code is unknown, the user can send the coordinates of the relevant station to get the requested rainfall information. An integrated meteorological database management program then searches for the closest stations, interpolates data from the stations prior to sending the results to the user who lodged the query.

By the second system, rainfall data are automatically sent to certain collaborating farmers. An automatic message execution program was developed so that these farmers will be sent data on their farm once weekly.

The third system provides information on the quantity of water applied to a field during an irrigation round. The plot features (location, area, available soil moisture, etc.) are stored in a database linked with a meteorological database. Farmers are identified by their telephone numbers when they place a call, and they give the number of the plots that are to be irrigated. A program calculates the irrigation needs for each plot on the basis of the most recent climatic data and sends the farmer information on the irrigation dosage to apply. To ensure efficient results, farmers must strictly comply with the recommendations because they are taken into consideration in the next SMS advice message. This test will soon be assessed in the field.

Agricultural machinery and land improvement training

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J.-L. Mazot
CIRAD

CIRAD's long experience with agricultural machinery is being promoted through training initiatives. For the sugarcane industry, training sessions organized for several professional subsectors are held regularly in Réunion, Mauritius and Guadeloupe. In Guadeloupe, we train SICA members and agricultural service companies that they oversee. In Réunion, we train technicians on becoming expert advisors within the framework of the European land improvement funding procedures. In Martinique, a project is currently being drawn up and will be operational in late 2006.

Partners of these initiatives are mainly from the industrial sector (Centre technique de la canne et du sucre, CTCS; Centre technique interprofessionnel de la canne et du sucre, CTICS; Departmental Project Coordination Service) and large-scale farms (sugar and rum farms). In Mauritius, a centre is set up to train staff from farms and the sugar industry.

→ Réunion—land improvement supervisors

Within the framework of the European land improvement funding procedures launched on 1 January 2005, we were asked to train expert supervisors on preparing and managing these work sites.

This procedure involves farms, agricultural service companies and experts from the Departmental Project Coordination Service. These experts prepare requests for land development funding support, supervise the work and give their approval at the end of the job. We are in charge of the pilot phase of the procedure, which includes a training session for technicians to become future expert advisors.

In practice, these experts will work on projects to set up farms or projects to expand or redevelop the parcel plan on existing farms. The training provides technicians with skills for effective field assessments, on development techniques, on conditions required for mechanization, and on using tools required for preparing different projects (maps, measurement equipment, GPS, GIS). Following the session, they are able to:
– advise farmers wishing to present a project request
– analyse future work sites and propose initiatives to be carried out

– explain projects to companies which could submit tenders
– supervise, evaluate and approve the work.

The training session lasts 10 days and involves 12 trainees. Twenty-four technicians were trained in 2004 and 2005. A new session is already planned for late 2006.

→ Martinique—an agricultural machinery training project

In Martinique, CTCS asked us to develop agricultural machinery training sessions for people working in the agricultural sector (farmers and salaried farm workers, trainers, company senior staff, mechanics, etc.). This project integrates sustainable development practices at all levels: the use and 'environment-friendly' maintenance of tractors (fuel savings, oil changes, effluent management, etc.), safety guidelines, staff management, monitoring and integration of technological progress that could enhance the competitiveness of the sugarcane industry.

As an illustration, the educational aims for training sessions targeting users such as farmers, salaried employees of agricultural service companies or drivers and mechanics of contracting companies could be to instruct them on how:
– to efficiently use agricultural machinery (understanding and complying with pictograms, user's instructions, specific tools, field adjustments, self-management of cropping operations, daily maintenance, abnormal functioning, etc.)
– to assess the agricultural requirements of the crop so as to select adapted techniques and equipment
– to develop, set up and use an efficient system for written communication exchanges between mechanics (equipment specifications), drivers (log book), and head farmers (information sheets on jobs carried out and resources used)
– to efficiently use on-board monitoring systems.

In 2005, the project pinpointed educational objectives for different stakeholders. The training sessions will begin in 2006-2007.

Promising sugarcane varieties in Guadeloupe

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UPR 75 Genetic Improvement of Vegetatively Propagated Crops
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UPR 75
J.-C. Efile
UPR 5 Sugarcane Farming Systems
D. Roques
UPR 75

CIRAD's varietal improvement research group in Guadeloupe aims to regularly supply sugarcane growers with new efficient sugarcane varieties specifically adapted to the agricultural conditions of the areas in which they are to be grown.

This includes a breeding station with a sugarcane germplasm collection of around 1 500 accessions that also regularly benefits from a supply of new genotypes of agricultural and genetic interest from CIRAD's quarantine service in Montpellier. Every year, 15 000 seedlings (FR varieties) obtained by sexual hybridization are put through a breeding programme involving six selection stages lasting a total of about 15 years. Around 50 foreign varieties are also introduced yearly in the fourth selection stage. These foreign varieties are mainly from the West Indies Central Sugar Cane Breeding Station in Barbados, with which CIRAD has signed a scientific collaboration contract, and also from other breeding centres, often subject to specific conditions for their subsequent commercial use.

Promising varieties are selected at the end of the fifth selection stage. The trials are carried out on Vertisols in Grande-Terre, where rainfall patterns are highly variable, and on ferralitic soils in northern Basse-Terre under high rainfall conditions. In this programme, the Marie-Galante sugarcane growing area is considered to mirror the cropping conditions in Grande-Terre, and selected varieties are also grown in this area. Breeding trials are carried out in collaboration with several agricultural organizations, including SCEA Aiguebel, the Convenance agricultural school in Basse-Terre, Gardel SA, and the INRA research unit at Godet in Grande-Terre.

Promising varieties obtained through these selection stages have agricultural features and pest resistance traits which are considered to be equivalent to or better than those of currently cropped sugarcane varieties. They are disseminated to growers for testing in precommercial trials to assess their performances when grown on a large scale under regular cropping conditions. This participatory stage is essential for the certification of these varieties prior to their commercial release.

In 2005, 11 new promising varieties were proposed, including five varieties for Basse-Terre (DB86 84, B88 804, FR94 129, FR94 218, FR94 285) and six varieties for Grande-Terre and Marie-Galante (BJ82 119, BT87 220, B89 452, FR95 285, FR95 579, FR96 018) (Table 1). Five other varieties that were previously found to be promising are also currently being evaluated in participatory precommercial trials.

These varieties were presented to technicians of the cane-sugar-rum industry during a 1-day field visit held prior to the annual technical steering committee meeting (CORT, 13 December 2005) on the varietal improvement topic. The features of these varieties are detailed (in French) in the *Catalogue des variétés prometteuses en Guadeloupe* (P. Oriol, V. Virapin, D. Roques, 2005).

Decisions to certify these varieties are made by industry stakeholder members of the Commission paritaire interprofessionnelle de la canne et du sucre (CPICS) on the basis of the precommercial trial results. At this step, professional partnerships have to be strengthened so as to be able to make suitable choices of varieties to be developed. We thank all stakeholders of the cane-sugar-rum industry in Guadeloupe who participated in the selection of these varieties and whose support will ultimately help to diversify sugarcane variety patterns in the sugarcane cropping area.

Varieties	Millable cane yield	Extractible sucrose content	Sugar yield	Adaptation to mechanical harvesting	Comments
BT83 339	+	=	+	=	Thick stalks
DB86 84	=	+	=	=	Thick stalks
B88 804	+	-	+	+	Uniform stalks
B88 1104	=	=	=	+	Vigorous growth
B91 948	=	=	=	+	Susceptible to scald
FR94 129	=	+	+	+	Rapid growth
FR94 218	=	=	=	+	Greenish yellow leaves
FR94 295	+	=	+	=	Vigorous growth

Table 1.

Promising sugarcane varieties at CIRAD, Guadeloupe: main agronomic features relative to the cv R570 control at Basse-Terre (+ higher, = equivalent, - lower than the control in the area).

Table 2.

Promising sugarcane varieties at CIRAD, Guadeloupe: main agronomic features relative to the cv B80 689 at Grande-Terre and Marie-Galante (+ higher, = equivalent, - lower than the control in the area).

Varieties	Millable cane yield	Extractible sucrose content	Sugar yield	Adaptation to mechanical harvesting	Comments
BJ82 119	=	+	+	=	Adherent straw
BT87 220	+	+	+	=	Vigorous growth
B89 452	+	=	+	+	Vigorous growth
FR88 196	=	=	=	+	High yielding in dry years
FR89 423	+	=	+	=	Vigorous growth
FR89 746	+	=	+	=	Regular emergence
FR95 285	+	=	+	=	High tillering
FR95 579	+	+	+	=	High tillering
FR96 018	+	+	+	+	Susceptible to scald

Certification of CIRAD's sugarcane quarantine unit in Montpellier

J.-C. Girard
UMR BGPI
P. Rott
UMR BGPI

CIRAD's sugarcane quarantine unit in Montpellier was officially certified after all imports of sugarcane into Europe for planting purposes was prohibited due to the risk of introducing quarantine parasites. The quarantine unit was audited during the first quarter of 2005 and granted a 5-year certification.

→ Around a hundred varieties tested yearly

CIRAD's sugarcane quarantine unit imports around a hundred varieties of sugarcane and other related botanical genera (e.g. *Miscanthus* and *Erianthus*) in the form of cuttings or micropropagated plants. The health status of these varieties is monitored to ensure that they are free of serious diseases and pests which, if present, are eliminated. Disease-free plants are then released for distribution in some 15 countries worldwide (Africa, Central America, South America, Asia and Australia). Sugarcane quarantine involves two main phases: a first so-called 'European' quarantine phase and a second 'international' phase.

→ European quarantine phase

The first European phase is carried out in compliance with EU legislation on plant imports. The aim is to avoid all risk of introducing quarantine organisms that could be carried by sugarcane into Europe, i.e. three insects (*Exomala orientalis, Spodoptera frugiperda* and *Opogona sacchari*) and two nematodes (*Longidorus* sp. and *Xiphinema americanum*). In practice, this phase is conducted in the BL2-P laboratory unit, where received cuttings are treated with an ovicide and left for 8-10 days to germinate so as to avoid all risk that any of the target insect pests will hatch. The two nematodes only attack roots and thus cannot be carried on cuttings or micropropagated plants, so no special treatments are carried out against these pests.

→ International quarantine phase

The second international phase is carried out to meet requirements of the different countries to which the varieties are sent, i.e. cuttings must be free of sugarcane diseases. Varieties released from European quarantine are grown in greenhouses for two successive cropping cycles (9-12 months per cycle). Preventive or curative chemical (pesticides) or physical (heat) treatments are conducted. Varieties may undergo *in vitro* apical meristem culture, when necessary, to eliminate certain viruses. During the first cycle, many disease screening tests are carried out that currently concern six viruses, two bacteria and two phytoplasmas. The main aim of the second cycle is to multiply a sufficient number of plants per variety to get enough cuttings for export. In some cases, varieties are micropropagated after the second cycle to obtain quarantine-certified micropropagated plants. At the end of the second cycle, these varieties are exported, accompanied by documents certifying that they are disease-free.

→ Quarantine—linking research and application

Sugarcane quarantine involves highly applied activities (germplasm transfer under safe phytosanitary conditions), so it is an important link between research and application. It makes effective use of research results by applying diagnostic and pathogen-detection techniques, or tailoring them to specific needs. Conversely, research is called upon when new diseases (or variants of know pathogens) arise, so as to be able to identify them, develop reliable routine detection techniques and efficient control methods. This has been the case over the last 10 years with respect to the *Sugarcane yellow leaf virus*, *Sugarcane mosaic virus* and *Sugarcane streak mosaic virus*.

Collaboration with Chinese scientists on sugarcane pathology

P. Rott
UMR BGPI

Within the framework of a cooperation agreement signed with the Yunnan Academy of Agricultural Sciences (YAAS, China) on 19 November 2004, CIRAD experts undertook a first visit in 2005 to meet with collaborators at YAAS and the Yunnan Sugarcane Research Institute (YSRI), and to discuss future sugarcane pathology collaborations.

Since 1999, YSRI has imported 94 FR varieties (produced by CIRAD, Guadeloupe) and 32 international varieties released from CIRAD's sugarcane quarantine unit. Of these varieties, FR93435 and FR93344 have already given promising results in tests conducted in Yunnan, and YSRI is interested in importing other FR varieties and exchanging varieties with CIRAD.

Several serious sugarcane diseases are present in Yunnan (smut, mosaic, etc.). YSRI places new sugarcane material in the quarantine greenhouses of YAAS to ensure that no new strains of pathogens already present will be introduced. A proposal was put forward to set up a joint research initiative to identify and characterise the causal agents of sugarcane mosaic disease in Yunnan and in other sugarcane-growing provinces in China.

Physiological factors associated with drought tolerance

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Breeding and selection of new drought-tolerant sugarcane varieties are priorities of CIRAD's varietal improvement programme. The aim is to produce high-yielding varieties that can be cultivated under the rainfed conditions of Guadeloupe, where there are substantial and frequent water shortages. Moreover, a better balance between water supply conditions and productivity could be achieved by exploiting tolerant varieties.

Few studies have focused on drought tolerance factors in sugarcane. However, it is known that a plant's adaptation to water stress does not solely depend on genetic factors associated with the plant but also on the interaction between these factors and environmental variables. In this setting, it is hard to determine the best selection traits and breeding strategies.

→ Leaf extension rate—a key indicator

The leaf extension rate (LER) is a relevant global indicator since it is the result of interactions between different plant traits and environmental variations. In maize, studies carried out by Reymond *et al.* (2003, 2004)[1] demonstrated that the regression between LER and the vapor pressure deficit (VPD), as well as with the soil water potential is linear and heritable. These results indicated that plants may respond to stress according to environmental variables. The performance of a genotype can therefore be predicted on the basis of LER for given VPD and water potential values.

→ Method based on maize research

On the basis of the results of research carried out on maize, two greenhouse experiments were conducted under controlled conditions at CIRAD, Guadeloupe, on 14 and 21 week-old plants. Three cultivars were grown in pots under drip irrigation: drought-tolerant cv ROC 8, susceptible cv B69 566 and a wild *Saccharum spontaneum* clone.

LER was calculated by the following equation:

dL/dt = LER = (T - T0) (a + bVPD +cY) (Reymond *et al.*, 2003)

1 Reymond M., Muller M., Leonardi A., Chacosset A., Tardieu F., 2003. Combining quantitative trait loci analysis and an ecophysiological model to analyze the genetic variability of the response of maize leaf growth to temperature and water deficit. Plant Physiology 131: 664-675.

Reymond M., Muller B., Tardieu F., 2004. Dealing with the genotype x environment interaction via a modelling approach: a comparison of QTLs of maize leaf length or width with QTLs of model parameters. Journal of Experimental Botany 55: 2461-6472.

where:

– a was estimated by measuring LER at night when there was no soil and air relative humidity deficit

– b was estimated by measuring LER during the day with variable temperature and relative humidity levels in plants without water stress

– c was estimated by measuring LER at night with variable soil water deficit levels and negligible VPD

– T0 was the temperature estimated at 12°C on the basis of temperature-dependent sugarcane growth measurements

– meristem temperature T, air temperature, relative humidity of the air and light intensity were recorded every 600 s

– VPD was calculated according to the method of Reymond *et al.* (2003)

– LER was calculated on the basis of leaf length measurements obtained at 6:30 a.m. and 5:45 p.m. (sunrise and sunset)

– water stress was induced by stopping irrigation

– the soil water potential Y was assessed on the basis of TDR probe measurements.

→ Marked predawn effect of the soil water potential

As expected, the results showed that the vapor pressure deficit (VPD) and the predawn soil water potential had marked effects on LER (Figure 1). However, the soil water potential had a much greater effect than VPD on LER. Plants reduced their LER when the water potential was low, whereas an increase in VPD only induced a slight decrease in LER, and the trend was similar for the three varieties, contrary to maize for which marked differences were noted.

The low variation in LER relative to VPD could be explained in different ways. First, under low VPD conditions, sugarcane leaves may curl but do not dry out. Secondly, whips effectively protect sugarcane stalk meristems from harsh environmental conditions, i.e. the meristem is saturated with water even at high VPD.

In young plantlets, under normal water supply conditions, the wild clone and two other sugarcane varieties had different LERs, whereas they were similar for all three varieties under water stress conditions. However, in older plants, the wild clone had a significantly higher LER than the other clones, even under substantial water stress, suggesting that *S. spontaneum* can continue growing with a water deficit, whereas the two other cultivars had stopped growing.

In contrast, at the point when they stopped growing (– 0.5 MPa), marked physiological differences were noted between varieties (greater leaf yellowing and drying in cv B69 566), suggesting that the water stress tolerance of cv ROC 8 is associated with its capacity to preserve its physiological integrity and not with its growth capacity under stress.

In conclusion, the predawn soil water potential after which the different genotypes stopped growing, as noted in the wild *S. spontaneum* clone, could serve as a selection indicator.

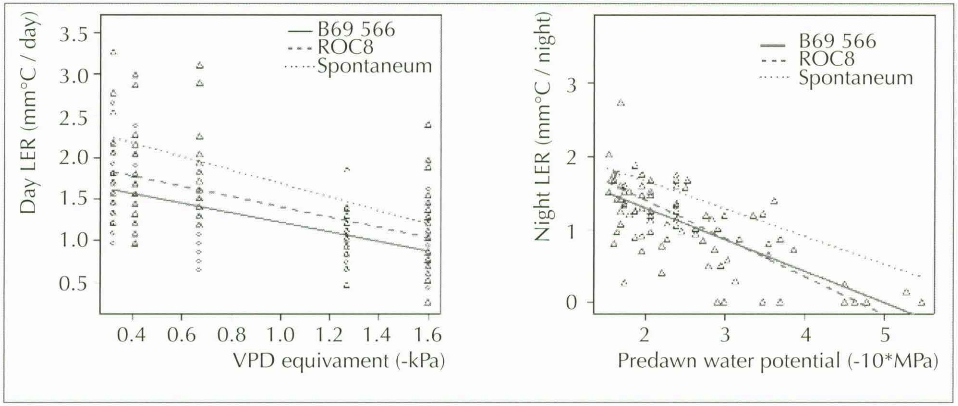

Figure 1. Leaf extension rate (LER in mm °C/time period) for the three studied clones (ROC 8, B69 566, wild clone) according to variations in the vapor pressure deficit (VPD) and the predawn soil water potential.
(lines represent linear regressions between LER and VPD, LER and the water potential for each variety)

➔ Prospects

Could the hardy 'growth capacity under high water deficit' trait be inserted in commercial clones without loss of their agronomic features? One option would be to develop specific genetic material via backcrossing interspecific hybrids that have different drought tolerance traits with a commercial cultivar. This strategy would reveal the effects of each trait on plant performance under water stress conditions. Further studies will be carried out on a larger population, as noted above, and on the mechanisms present and their variation in wild clones.

Role of silicon in sugarcane resistance to the African stalk borer *Eldana saccharina* (Lepidoptera: Pyralidae)

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Sugarcane is a major crop in South Africa, especially in Kwazulu-Natal and Mpumalanga provinces. Yearly domestic and world market profits from sugarcane are around 6.5 billion rand (€750 million). However, since 1970, the lepidopteran sugarcane stemborer *Eldana saccharina* Walker (Pyralidae) has inflicted heavy economic losses that are evaluated at 60 million rand a year (€7.5 million).

Silicon is naturally abundant in soil layers, but in South African sugarcane-growing areas 60% of the soils are sandy or acidic and little silicon is available for crops. In addition to this silicon deficiency, water supplies are sometimes low, thus further promoting stemborer infestations. The beneficial protective effects of silicon have been demonstrated in plant-insect interactions (Moraes *et al.*, 2004)[1]. Silicon was also found to be involved in the metabolic activity of plants, especially by activating the plant's natural defences against pests, e.g. against attacks by insects (Wang, 2005)[2], including *Eldana saccharina* (Keeping and Meyer, 2002; Kvedaras *et al.*, 2005)[3]. Other authors have shown that silicon applications can alleviate water stress by reducing plant evapotranspiration rates (Gao *et al.*, 2004)[4].

A 3-year (2004-2006) collaboration project involving SASRI and CIRAD was thus launched to study the combined effects of silicon and water stress on sugarcane resistance to *E. saccharina* attacks. Experiments were set up to address two research issues:

– What is the mechanism by which silicon induces sugarcane resistance to stemborer attacks?

– Does silicon induce stronger resistance to stemborer attacks in water stressed plants?

Novel results were obtained in 2004 at sites colonized by stemborer larvae—this research was carried out within the framework of the postdoctoral studies of the SASRI entomologist O.-L. Kvedaras (Kvedaras *et al.*, 2005). Here we summarize the main results obtained in 2005.

→ Experimental methods

A split-plot experimental design was used in a climate-controlled greenhouse at SASRI (Mount Edgecombe, South Africa). Four varieties were grown in pots: N21 and N33 (stemborer resistant), N11 and N26 (stemborer susceptible). For each

SASTA Kynoch Prize

This research topic won the Kynoch Prize after it was presented at the South African Sugar Technologists' Association (SASTA) Congress in July 2006 in Durban (South Africa).

variety, half of the pots were not supplemented with silicon, while 124 g of calcium silicate ($CaSiO_3$) was applied to each pot in the other half batch, i.e. a silicon content of 7.9% (equivalent to an input of 10 t/ha).

At 8.5 months, half of the plants were subjected to water stress by gradually reducing the water supply. At the end of the stress period, each stressed plant had formed four to five green leaves whereas nonstressed plants had formed 11 leaves.

At 12 months, plants in each pot were inoculated with 150 *E. saccharina* eggs. The stemborer larvae were then left to develop for 66 days (520 degree-days, 10°C temperature threshold) before the sugarcane plants were harvested for analysis. The following indicators were used to assess damage in these sampled plants: stalk length, total number of internodes, midstalk internode hardness, number of bored internodes, total length of internal damage and internal galleries. The number and weight of live larvae and pupae were also recorded as larva performance indicators. The plant silicon content was assessed *in vitro* in leaf samples.

→ Results—silicon enhances stemborer resistance in sugarcane

Regardless of the variety and water stress status, the stalk silicon content in silicon-supplemented plants was almost twofold higher than that in stalks of non-supplemented plants. In silicon 'enriched' plants, a significant reduction in stemborer performance and damage was noted. Stemborer damage was even found to be reduced to very low levels in susceptible water-stressed cultivars—equivalent to levels measured in resistant varieties subjected to water stress or not.

However, silicon inputs did not modify stalk hardness in any variety. This suggests that soluble silicon could have an active role in improving the plant's defence against infestations of this stemborer, in contrast with the hypothesis put forward previously that solid silicon deposits could provide a physical or mechanical barrier to larva penetration (Ishiguro, 2001)[5]. Concerning water-stressed plants, the lack of water might induce modifications in the silicon concentration and structure in plant tissues. These modifications could substantially boost the larva-penetration barrier effect, without modifying the tissue hardness. Another possibility is that the plant's natural chemical or physiological defence system could be strengthened, but further studies are required to clarify these mechanisms.

From a practical standpoint, these results (which still require confirmation) are promising in terms of enhancing field control of this pest. For instance, in rainfed crops grown on silicon-deficient soils in dry regions, silicon amendments could help to protect sugarcane plants—even susceptible cultivars—from stemborer infestations.

1 Moraes J.C., Goussain M.M., Basagli M.A.B., Carvalho G.A., Ecole C.C., Sampaio M.V., 2004. Silicon influence on the tritrophic interaction: Wheat plants, the greenbug *Schizaphis graminum* (Rondani) (Hemiptera: Aphididae), and its natural enemies, *Chrysoperla externa* (Hagen) (Neuroptera: Chrysopidae) and *Aphidius colemani* Viereck (Hymenoptera: Aphidiidae). Neotropical Entomology 33: 619-624.

2 Wang M.Q., 2005. Effect of complete silicon fertlizer on rice yield. Acta Agr Shanghai 21: 71-73.

3 Keeping M.G., Meyer J.H., 2002. Calcium silicate enhances resistance of sugarcane to the African stalk borer *Eldana saccharina* Walker (Lepidoptera: Pyralidae). Agricultural and Forest Entomology 4: 265-274.

Kvedaras O.L., Keeping M.G., Goebel R., Byrne M., 2005. Effects of silicon on the African stalk borer, Eldana saccharina (Lepidoptera: Pyralidae) in sugarcane. Proceedings of the South African Sugar Technologists' Association. vol. 79: 359-362.

4 Gao X., Zou C., Wang L., Zhang Fusuo, 2004. Silicon improves water use efficiency in maize plants. Journal of Plant Nutrition 27: 1 457-1 470.

5 Ishiguro K., 2001. Review of research in Japan on the roles of silicon in conferring resistance against rice blast. *In* Le Datnoff , G.H. Snyder and G.H. Korndorfer (Eds), Silicon in Agriculture: Studies in Plant Science, 8: 277-291. Elsevier Science, Amsterdam, The Netherlands.

→ Prospects—studying silicon in sugarcane stalks

Further experiments are under way with a dual aim, i.e. to locate silicon deposits in sugarcane stalks that could be involved in establishing a barrier mechanisms to *E. saccharina* larva penetration and, secondly, to determine the nature of this barrier (physical, chemical, or both). If such silicon deposits increase resistance to the borer, then the structure likely differs in silicon-treated and untreated sugarcane. These differences could be characterized by standard analytical techniques. The energy-dispersive X-ray microanalysis (EDX) technique could be used to view silicon deposits in plant tissues. A preliminary assessment of silicon-treated and untreated plants revealed that concentrations of this element were higher in external than in internal sugarcane tissues. Internal and external sugarcane tissues will thus be analysed to detect sites where silicon concentrations are highest. To facilitate these investigations, CIRAD is collaborating with Professor Mark Laing (University of Kwazulu Natal), who is studying the role of silicon in plant-pathogen interactions.

Germplasm used to enhance sugarcane resistance to the spotted stemborer *Chilo sacchariphagus* (Bojer)

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The spotted stemborer *Chilo sacchariphagus* (Lepidoptera) is a major sugarcane pest in the Indian Ocean and Asian regions, and it was recently introduced in southern Africa. The different levels of damage noted in two of the most commonly cropped varieties in Réunion (cv R570 less infested than cv R579) illustrates the genetic variability in the susceptibility of sugarcane to *C. sacchariphagus*. This genetic resistance is a key component in the integrated management of this pest and complements other strategies such as biological control. The aim of research under way in Réunion is to provide breeders with sources of resistance and effective varietal assessment and screening methods. Research is under way on three aspects:

- assessment of variations in resistance to *C. sacchariphagus* within the *Saccharum* genus
- analysis of resistance mechanisms
- detection of molecular markers of resistance.

→ Genetic variability of resistance

Development of a leaf damage scale

Leaf damage caused by young stemborer larvae can now be assessed according to a damage scale. The top five whole leaves are monitored and each leaf is scored. This scale was developed by analysing the relationship between the total lesion area per leaf and the number of different lesion types (pinholes, shotholes, circular lesions, elongated lesions classified by size). The best relationship was obtained by counting elongated lesions of more than 10 mm long on whole leaves (Table 1).

Reliability of damage scoring criteria

The aim was to assess the reliability of methods for measuring resistance to spotted stemborers and select those with the best cost/reliability ratio for their use in a breeding programme. The study involved three trials conducted at the Centre d'étude, de recherche et de formation de La Réunion (CERF), comparing elite material at the end of the breeding process. In conclusion, the stalk puncture rate, which is the least costly damage variable to implement, classified clones as efficiently as all other more complex variables. However, the leaf damage scores were not closely genetically correlated with stalk damage, so it seems that this

Table 1.

Scale of leaf damaged caused by spotted stemborers. Observations on the top five whole leaves, with each leaf scored separately.

Score	Damage description
0	No signs of attack on the top five leaves
1	Signs of attack without elongated lesions
2	1-2 elongated lesions more than 10 mm long
3	3-4 elongated lesions more than 10 mm long
4	5-6 elongated lesions more than 10 mm long
5	7-8 elongated lesions more than 10 mm long
6	9-10 elongated lesions more than 10 mm long
7	11-12 elongated lesions more than 10 mm long
8	13-14 elongated lesions more than 10 mm long
9	≥ 15 elongated lesions more than 10 mm long

factor cannot be used for varietal screening. Finally, there seemed to be a positive genetic correlation between stalk damage levels and the vegetative vigour of clones. This correlation highlighted that the most productive varieties had the highest damage levels, and a specifically adapted statistical treatment would now be required to assess clone resistance without bias.

This methodical study on resistance measurement criteria is still under way in multisite trials at CERF, with the aim of better analysing the relationship between vegetative vigour and damage levels.

→ Three levels of resistance

A subpopulation of 35 sugarcane clones from the CERF collection of 456 international clones in Réunion was screened to assess stemborer resistance patterns and mechanisms. The results showed that the extent of resistance variations in this subpopulation was higher than that between cvs R570 and R579. Plants seemed to express this resistance at three levels:
– when young borer larvae feed on the leaves
– when the larvae move from the leaves to the stalk
– when the larvae puncture the stem.

The lack of correlation between these three resistance levels suggests that they are controlled by three separate genetic mechanisms.

Different amounts of leaf damage were noted at the first resistance level. This could be associated with the attractiveness of clones for adults or young larvae or to the mortality of these larvae.

The second level of resistance was noted when the larvae moved from the leaves to the stalk. There was a significant difference in between-cultivar responses, i.e. more worms reached the stem on cv R579 than on cv R570. This should be compared with previous results on the barrier function of leaf sheaths in cv R570 resistance (see the CIRAD *Sugarcane Annual Report 2004*).

At the third level of resistance, larvae were hampered from boring galleries once they had reached the stem. This mechanism was generally correlated with a reduction in the mean gallery length. This resistance could be associated with the stem hardness, which is a stemborer resistance factor that has already been pointed out in the literature.

In 2006, studies were launched on resistance mechanisms by assessing subpopulations in the field and conducting bioassays (choice and no-choice tests in petri dishes, greenhouse artificial infestations) with the aim of confirming the presence of different resistance levels in tissues (leaf blades, leaf sheaths and stem) and studying their expression modes (antibiosis, antixenosis).

→ Resistance QTLs identified in cv R570

An initial study was conducted to detect stemborer resistance QTLs in a population of 148 clones that were previously obtained by selfing cv R570 clones and genotyped with 1 221 AFLP markers. Phenotyping was performed in a trial in Réunion. No significant genotypic variability was observed with respect to leaf damage. However, the analysis revealed a significant correlation between stem damage (number of attacked internodes) and 32 markers. These encouraging results are to be confirmed in further trials.

Identifying genes involved in the pathogenicity of *Xanthomonas albilineans*

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PhD thesis studies are under way with the aim of identifying genes involved in the pathogenicity of *Xanthomonas albilineans*, and some of the results have already been summarized in previous CIRAD Sugarcane Annual Reports.

Many genes involved or potentially involved in the pathogenicity of plant pathogenic bacteria have already been identified. These genes code for different protein secretion systems, exopolysaccharides, virulence factors, toxins, cell-wall degradation enzymes, cell mobility and motility factors, and adhesion factors. In contrast with most plant pathogenic bacteria, no *hrp* or *avr* genes were detected in *Xanthomonas albilineans,* which is the causal agent of sugarcane leaf scald. However, this pathogen produces a pathotoxin called albicidin, which is responsible for leaf scald symptoms. All genes involved in albicidin biosynthesis in the Xa23R1 strain from Florida were recently cloned and sequenced. Variations in these biosynthesis genes were not, however, found to be correlated with variations in *X. albilineans* pathogenicity.

In this study, we tried to identify new genes involved in *X. albilineans* pathogenicity. Different methods were used to assess 19 *X. albilineans* strains able to colonize sugarcane plants and produce leaf scald symptoms to different extents. *In vitro* albicidin production varied with the different *X. albilineans* strains, but they all had the same RFLP profile when albicidin biosynthesis genes were used as probe. All strains were also found to have the same genetic profile when assessed by pulsed-field electrophoresis. However, AFLP analysis using 16 selective primer combinations after total genomic DNA digestion with *Sac*I et *Msp*I revealed some variation among strains, but no correlation between this genetic variation and *X. albilineans* pathogenicity variation was noted.

Forty primer pairs were then designed for PCR amplification of 40 genes involved in the pathogenicity of bacterial species closely related to *X. albilineans,* especially *X. campestris* pv. *campestris*. Only three genes (*pilB, rpfA* and *xpsE*) could be amplified with total genomic DNA from nine *X. albilineans* strains able to colonize sugarcane plants and produce leaf scald symptoms to different extents in Guadeloupe. The nucleotide sequences of these genes were identical in all *X. albilineans* strains and a phylogenetic study conducted using these sequences confirmed that *X. albilineans* belongs to the *Xanthomonas* genus. The fact that no

PhD thesis on the pathogenicity of *Xanthomonas albilineans*

Champoiseau P., 2006. *Xanthomonas albilineans*, l'agent causal de l'échaudure des feuilles de la canne à sucre : caractérisation et variabilité des bases génétiques du pouvoir pathogène, en Guadeloupe et dans le monde. PhD thesis in Life Sciences option Phytopathology, Université des Antilles et de la Guyane, Pointe-à-Pitre, Guadeloupe, France, 171 p.

amplification products were obtained with 37 primer pairs suggests that the genes involved in *X. albilineans* pathogenicity significantly differ from those of other closely related pathogens. Complete sequencing of the *X. albilineans* genome is under way at Génoscope (Centre national de séquençage in Evry, France) and represents a key step in unravelling the pathogenicity of this sugarcane pathogen.

Genetic diversity of *Sugarcane yellow leaf virus*, causal agent of yellow leaf

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Studies are underway within the framework of a PhD thesis entitled "Genetic diversity and variation in pathogenicity of *Sugarcane yellow leaf virus* (SCYLV), the causal agent of sugarcane yellow leaf". Results obtained in 2003 and 2004 were reported in previous CIRAD Sugarcane Annual Reports. In 2005, results confirmed that there are several SCYLV genotypes and their geographic distributions were studied.

A large part of the genome of 43 SCYLV isolates from Réunion and 17 isolates from various other parts of the world were amplified by RT-PCR, cloned and sequenced. Phylogenetic analysis of the determined sequences and 11 additional sequences from the GenBank database revealed that these SCYLV isolates are distributed in different phylogenetic groups or are unique genetic variants. Most isolates from Réunion were found to be in phylogenetic groups that contained no isolates from other origins. Four SCYLV genotypes were defined: BRA for Brazil, CUB for Cuba, PER for Peru, and REU for Réunion (which prevails on this island). The biological explanation on the existence of these SCYLV genotypes has yet to be determined.

The geographical distributions of the four genotypes BRA, CUB, PER and REU were studied. Specific primer pairs were designed to differentiate these four genotypes by RT-PCR. For each genotype, a single genome fragment was amplified, except for BRA and PER, which are phylogenetically very close and designated under the genotype name BRA-PER. These primer pairs were used in RT-PCR analyses to identify SCYLV genotypes from 18 regions worldwide—245 infected leaf samples were analysed. The results demonstrated that several SCYLV genotypes can coexist in the same sugarcane growing area or in the same plant. However, in some geographical areas, only one genotype or one major genotype was present. The BRA-PER genotype was detected in the 18 geographical regions surveyed. The CUB genotype was detected in only four regions, i.e. Brazil, Colombia, Cuba and Guadeloupe. REU was detected only in Brazil, Guadeloupe, Mauritius and Réunion. The three genotypes were detected in cultivars bred in Guadeloupe, highlighting that they were transmitted locally. However, only BRA-PER and CUB were present in cultivars bred in Brazil, whereas the REU genotype was identified in cv R570 samples imported from Réunion. Similarly, BRA-PER and REU genotypes were present in Réunion, but BRA-PER was not found to spread on the island. The presence of several SCYLV genotypes in Brazil, Colombia, Guadeloupe, Mauritius and Réunion suggests that either different virus introductions occurred or that the virus evolved in several ways after its introduction in this new environment.

Identification of chromosome regions involved in smut resistance

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Sugarcane smut, caused by the *Ustilago scitaminea* Syd. fungus, occurs in most sugarcane growing regions. Breeding sugarcane for smut resistance is efficient but requires large-scale testing and the genetic determinism of this resistance has not yet been clarified. Two strategies were used to identify chromosome regions involved in smut resistance:
– QTL mapping in a biparental cross between the resistant cv R570 and the highly susceptible cv MQ 76/53
– an association study in a population of sugarcane cultivars assessed for smut resistance in Burkina Faso.

After constructing the genetic map of the biparental cv R570 x MQ 76/53 hybrid, field and greenhouse tests were carried out using different inoculation methods in order to analyse smut resistance in 198 progeny clones. The phenotype frequencies noted in all of these tests were markedly shifted in favour of resistance, thus highlighting the presence of several dominant resistance factors.

QTL analysis using 1 666 available polymorphic markers led to the detection of a certain number of weak-effect QTLs that are involved in resistance. Moreover, in the cultivar population (consisting of a highly smut-resistant subpopulation and a highly susceptible subpopulation), the study of associations between molecular markers and smut resistance highlighted some haplotypes associated with resistance. A comparison of the results obtained by these two approaches revealed two common genome regions that are involved in resistance. Although the genetic determination of resistance to smut has yet to be clearly understood, association studies in sugarcane do seem to offer considerable potential. A much higher number of markers should, however, be analysed to be able to achieve optimal results.

PhD thesis on the genetics of smut resistance

Raboin L.-M., 2005. Génétique de la résistance au charbon de la canne à sucre causé par *Ustilago scitaminea* syd. : caractérisation de la diversité génétique du pathogène, cartographie de QTL dans un croisement bi-parental et étude d'associations dans une population de cultivars modernes. PhD thesis in Integrative Biology, Agro.M, Montpellier, France; CIRAD, UMR PVBMT, Saint-Pierre, Réunion, France, 119-[10] p.

Physical mapping of the region containing the *Bru1* rust resistance gene

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A major rust resistance gene (*Bru1*) was identified in the R570 sugarcane cultivar. Positional cloning of the *Bru1* gene is being carried out in a project funded by the International Consortium for Sugarcane Biotechnology (ICSB).

Physical mapping of the *Bru1* locus is under way. BACs belonging to seven different haplotypes were identified by screening a cv R570 BAC library. Only one BAC was found to span the entire target region for certain homo(eo)logous haplotypes, whereas only one BAC belonged to the *Bru1*-bearing haplotype and did not span the entire target region.

A new library was thus produced from four progeny of selfed cv R570 individuals bearing two copies of the *Bru1* gene. Three new nonoverlapping BACs belonging to the target haplotype were first identified. Chromosome walking was thus performed with the aim of covering the entire region containing *Bru1*. BAC-end sequences and BAC subclones from the target region were then used to detect new overlapping BACs. Eight BACs forming three contigs belonging to the target haplotype were ultimately identified, but two remaining areas were not covered. In addition to the physical mapping, a more detailed genetic map was obtained in the target region with 13 new markers, including 12 that cosegregate with *Bru1*. Moreover, some probes developed from BACs of the target haplotype did not hybridize on BACs belonging to homo(eo)logous haplotypes. This highlighted the presence of an insertion in the target haplotype that was responsible for a reduction in the recombination rate in the target region.

Four BACs spanning part of the target haplotype, six BACs representative of other identified haplotypes, and three sorghum BACs covering the orthologous region are currently being sequenced at Génoscope (Centre national de séquençage, Evry, France).

PhD thesis on the genetics of rust resistance

Le Cunff L., 2005. Contribution au clonage positionnel d'un gène de résistance à la rouille chez un haut polyploïde, la canne à sucre ; exploitation des relations synténiques avec le sorgho et le riz. PhD thesis in Biochemistry and Molecular Biology, Université Montpellier II, UMR PIA, CIRAD, Montpellier, France, 155 p.

Appendices

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↗ Teams involved in sugarcane research in 2005-2006

See research unit websites for further information.

Research unit*	Unit leader	Sugarcane teams
UPR 5	Bernard Siegmund (Pascal Marnotte from 1 January 2006)	● Réunion **Scientists:** Eric Bappel (PhD thesis), Pierre-François Chabalier, Jean-Louis Chopart, Caroline Lejars, Valentine Lebourgeois (VCAT), Jean-François Martiné, Jérôme Masson (VCAT), Roland Pirot, Christophe Poser, Pierre Todoroff **Technicians:** Catherine Ango (assistant), Jean-Luc Brossier, Dany Deurveilher, Jean-Jo Esther, Lilian Gauvin, Ginot Gauvin, Jean-Maurice Guéno, Emmanuel Horau, Michel Rosaire Jeannette, Lionel Le Mezo, Hugues Lombard, Mickaël Mezino, Bernard Mouny-Latchimy, Raymond Nativel, Alix Rassaby, Aurélien Velle, Grégory Vignay
		● Guadeloupe **Scientists:** Jean-Cyril Dagallier, Denis Pouzet, Pierre Todoroff **Technicians:** Annick Annette, Omer Calvados, Eugène Catan, Jean-Marie Coupan, Jean-Claude Effile, Alain Kandassamy, Nadia Lubin, Elie Nudol, Sylvie Perrot
		● Senegal **Scientist:** Daniel Marion
		● Montpellier **Scientists:** Marinus Brouwers, Régis Goebel, Pierre Langellier, Pascal Marnotte, Bernard Vercambre **Technicians:** Alain Carrara, Dominique Héraud (assistant)
UPR 13	Philippe Letourmy	● Montpellier **Scientists:** Michel Giner, Sabine Laurent (PhD thesis), Jean-Baptiste Laurent, Jean Parriaud **Technician:** Sandrine Auzoux
UPR 43	Patrick Dugué	● Montpellier **Scientist:** Pierre-Yves Le Gal
UPR 75	Robert Domaingue	● Guadeloupe **Scientists:** Gemma Arnau, Patrice Champoiseau (PhD thesis), Jean-Heinrich Daugrois, Carine Edon (PhD thesis), Jean-Yves Hoarau, Philippe Oriol, Danièle Roques **Technicians:** Rosiane Boisne-Noc, Jean-Louis Calvados, Murette Cadet, Martin Carbel, Sylvère Carmel, Georges Gelabale, Jocelyne Geoffroy, Chantal Giougou, Marie-Claire Gravillon, Antoinette Joseph, Steeve Joseph, Eric Maledon, Solène Mayo, Patricia Navis, Marie-Claire Planchet, Marc Ragouton, Jocelyne Sapotille, Antoinette Tifeau, Lyonel Toubi, Vanessa Virapan

Research unit*	Unit leader	Sugarcane teams
UPR 78	Hervé Saint Macary	● Montpellier **Scientists:** Thabit Elsayed (PhD thesis), Denis Montange, Robert Oliver
UMR BGPI	Jean-Loup Notteghem	● Montpellier **Scientists:** Youssef Abu-Ahmad (PhD thesis), Jean-Claude Girard, Philippe Rott **Technicians:** Jean-François Bousquet, Marie-José Darroussat, Emmanuel Fernandez, Rémi Habas, Marc Muller
UMR PIA	Jean-Christophe Glaszmann	● Montpellier **Scientists:** Loic Le Cunff (PhD thesis), Angélique D'Hont, Jérôme Pauquet **Technicians:** Céline Cardi, Olivier Garsmeur
UMR PVBMT	Bernard Reynaud	● Réunion **Scientists:** Laurent Costet, Samuel Nibouche, Louis-Marie Raboin **Technicians:** Cedric Lallemand, Magali Payet, Irénée Promi, Hughes Telismart, Richard Tibère
UMR TETIS	Pascal Kosuth	● Montpellier **Scientists:** Agnès Bégué, Pascal Degenne, Vianney Houles (postdoc)

* **Names of internal research units (UPR) and joint research units (UMR):**

– **UPR 5,** Sugarcane Farming Systems
www.cirad.fr/ur/systemes_canniers

– **UR 75,** Genetic Improvement of Vegetatively Propagated Crops
www.cirad.fr/ur/multiplication_vegetative

– **UPR 13,** Decision Support and Biostatistics
www.cirad.fr/ur/biostatistique

– **UPR 43,** Innovation and Dynamics of Farming Systems
www.cirad.fr/en/pg_recherche/ur.php?id=127

– **UPR 78,** Environmental Risks of Recycling
www.cirad.fr/ur/recyclage_risque

– **UMR BGPI,** Biology and Genetics of Plant-Pathogen Interactions for Integrated Protection, CIRAD, Agro.M, INRA, Montpellier, France
http://umr-bgpi.cirad.fr/index_uk.htm

– **UMR PVBMT,** Plant Communities and Biological Invaders in Tropical Environments, CIRAD, Université de La Réunion, Réunion, France
www.univ-reunion.fr/pvbmt/english.html

– **UMR PIA,** Polymorphisms of Interest in Agriculture, CIRAD, Agro.M, INRA, Montpellier, France
http://umr-pia.cirad.fr

– **UMR TETIS,** Spatial Information and Analysis for Territories and Ecosystems, CIRAD, CEMAGREF, ENGREF, Montpellier, France
www.cirad.fr/en/pg_recherche/ur.php?id=129

↗Publications

← High impact peer reviewed periodicals

2006

→ Abu Ahmad Y., Rassaby L., Royer M., Borg Z., Braithwaite K.S., Mirkov E., Irey M., Perrier X., Smith G., Rott P., 2006. Yellow leaf of sugarcane is caused by at least three different genotypes of sugarcane yellow leaf virus, one of which predominates on the Island of Réunion. *Archives of virology* 151 (7): 1355-1371.

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→ Champoiseau P., Daugrois J.-H., Pieretti I., Royer M., 2006. High variation in pathogenicity of genetically closely related strains of *Xanthomonas albilineans,* the sugarcane leaf scald pathogen, in Guadeloupe. *Phytopathology* 96 (10): 1081-1091

→ Conlong D.E., Goebel R., 2006. *Trichogramma bournieri* (Pintureau & Babault) (Hymenoptera: Trichogrammtidae) and *Chilo sacchariphagus* Bojer (Lepidoprera: Crambidae) in sugarcane in Mozambique: A new association. *Annales de la société entomologique de France* 42 (3-4): 417-422.

→ Falloon T., Henry E., Davis M. J., Fernandez E., Girard J.-C., Rott P., Daugrois J.-H, 2006. First report of *Leifsonia xyli* subsp. *xyli,* causal agent of ratoon stunting of sugarcane, in Jamaica. *Plant disease* 90 (2): 245.

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→ Reay-Jones F., Rochat J., Goebel R., Tabone E., 2006. Functional response of *Trichogramma chilonis* to *Galleria mellonella* and *Chilo sacchariphagus* eggs. *Entomologia experimentalis et applicata* 118 (3).

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→ Daugrois J.H., Hoy J.W., Griffin J.L., 2005. Protoporphyrinogen oxidase inhibitor herbicide effects on pythium root rot of sugarcane, *Pythium* species, and the soil microbial community. *Phytopathology* 95 (3): 220-226.

→ D'Hont A., 2005. Unraveling the genome structure of polyploids using FISH and GISH: Examples of sugarcane and banana. *Cytogenetic and genome research* 109 (1-3): 27-33. URL: http://dx.doi.org/10.1159/000082378.

→ International Rice Genome Sequencing Project (auquel a participé D'Hont A.), 2005. The map-based sequence of the rice genome. *Nature* 436: 793-800. URL: http://dx.doi.org/10.1038/nature03895.

→ Reffay N., Jackson P.A., Aitken K.S., Hoarau J.Y., D'Hont A., Besse P., Mc Intyre C.L., 2005. Characterisation of genome regions incorporated from an important wild relative into Australian sugarcane. *Molecular breeding* 15: 367-381. URL: http://dx.doi.org/10.1007/s11032-004-7981-y.

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→ Low impact peer reviewed periodicals

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↗Scientists and visitors hosted in 2005-2006 (partial list)

→ Jacquemin Philippe et Verschoere Nicolas (c/o R. Goebel), directeur agronomique et directeur adjoint du site sucrier de Kivulu Ngongo (groupe belge Finasucre), République démocratique du Congo. 16 septembre 2005. Présentation des activités « canne » du CIRAD et renforcement des liens, en particulier sur les aspects quarantaine, Montpellier, France.

→ Saeed Ibrahim (c/o R. Goebel, M. Brouwers, R. Domaingue), directeur du département recherche de Kenana Sugar Company, Soudan, du 30 septembre au 13 octobre 2005. Revue des activités sur la canne à sucre au CIRAD, projet de contribution à un contrat de collaboration. Montpellier, France.

→ Abaad Mohamed (c/o R. Goebel), agronome du Centre technique des cultures sucrières (CTCS Maroc) et doctorant de l'Upr 5 systèmes canniers (c/o J.F. Martiné), du 12 au 23 décembre 2005. Présentation des activités « canne » CIRAD et CTCS, La Réunion.

→ Snyman Hennie, Derek Niekerk, Webb Brian (c/o C. Poser), directeurs TSB Booker Tate, Afrique du Sud. Présentation des activités liées à la canne au CIRAD pour collaborations éventuelles au travers du groupe Quartier français, le 24 octobre 2005 à La Réunion.

→ Délégation de Tanzanie : Mme A.B. Uronu, Tropical Pesticides Research Institute (TPRI, Tanzanie), M. Juhudi Y. Chambi, Sugarcane Research Institute (SRI, Tanzanie), M. Jean-François Lagesse, TPC Limited, M. Jean Robert Lincoln, Ciel Agro-Industry (c/o C Poser, L. Costet). Présentation des activités du CIRAD, de l'UMR PVBMT, et visite de BETEL REUNION SA à Sainte-Suzanne, 18 et 19 avril 2005.

→ Secrétaires permanents à l'Agriculture de Sainte-Lucie, Saint-Vincent et les Grenadines, Grenade. Directeurs de l'agriculture de la Dominique, Saint-Vincent et les Grenadines, Saint Kitt's. Officier de liaison d'Antigua et Barbuda (c/o P. Todoroff). Au CIRAD en Guadeloupe.

→ Délégation sud-africaine de la Transvaal Sugar Limited (Transvaal Suiker Beperk, TSB) (c/o L. Costet) : présentation des activités et des résultats UMR PVBMT La Réunion, et de la plateforme technique du Pôle 3P Saint-Pierre à La Réunion, le 25 octobre 2005. La Réunion.

→ Rambaranny Lydie, Caisse Malgache de la canne et du sucre de Madagascar (c/o R. Domaingue), au CIRAD à Montpellier, France.

→ Ming Ray et Nagai Chifumi, généticiens sélectionneurs canne à sucre à Hawaï (c/o R. Domaingue) au CIRAD à Montpellier, France.

→ Accueil de missionnaires des sucreries de République Démocratique du Congo à Montpellier (collaboration CIRAD) (c/o R. Domaingue).

→ M. Imtiaz Ahmed Khan, Nuclear Institute of Agriculture, (c/o R. Domaingue) au CIRAD à Montpellier, France, 14 juin 2006.

→ Professeur Gassim et M. Osman, Université de Gezira, Soudan (c/o R. Domaingue) au CIRAD à Montpellier, France, 13 juillet 2006.

→ M. Nauman Kkan, Groupe ALMOIZ, Pakistan, (c/o R. Domaingue) au CIRAD à Montpellier, France, 05 Octobre 2006.

→ M. George Enoch Okwach, Kenya Sugar Research Foundation, Kenya (c/o R. Domaingue) au CIRAD à Montpellier, France, 27 novembre 2006.

→ M. Gervais Nicolin, Somdiaa, France, (c/o R. Domaingue) au CIRAD à Montpellier, France.

→ M. Geng Huai Jian, directeur général de la Yunnan Yinmore Sugar Industry Company (c/o D. Roques, P. Oriol) le 13 septembre 2005 : présentation des activités de recherche canne à sucre en Guadeloupe.

→ Comité de coordination de la Carribean Food Crop Society (CFCS) (c/o D. Roques, P. Oriol) le 25 février 2005 : visite de la station de Roujol en Guadeloupe et présentation des programmes de recherche.

→ Visite des étudiants en BTSA 2e année du Lycée agricole de Baie-Mahault (c/o D. Roques) le 20 avril 2005, station de Roujol, Guadeloupe.

→ M. Mangin (DAF, Guadeloupe) (c/o D. Roques), le 21 avril 2005 : contrôle de l'utilisation des fonds européens, à la station de Roujol, Guadeloupe.

→ M. Hellmann et B. Siegmund (c/o D. Roques), direction du CERF de La Réunion, du 20 au 27 octobre 2005 : discussion sur les collaborations CERF - CIRAD et relations avec la filière canne, à la station de Roujol, Guadeloupe.

→ Délégation de responsables et techniciens de la filière canne de Guadeloupe (c/o D. Roques) le 06 décembre 2005 : visite du dispositif d'amélioration variétale et présentation sur le terrain des variétés prometteuses, à la station de Roujol, Guadeloupe.

↗Acronyms

AFCAS	Association française de la canne à sucre, France
AFLP	amplified fragment length polymorphism
AGRIGUA	Association guadeloupéenne de recueil d'informations géographiques d'utilité agricole, Guadeloupe
Agro.M	Ecole nationale supérieure agronomique de Montpellier, France
AUF	Agence universitaire de la francophonie
BAC	bacterial artificial chromosome
BTS	brevet de technicien supérieur (advanced vocational training certificate), France
CAP	Common Agricultural Policy (EU)
CASI	compact airborn spectrographic imager
cDNA	complementary DNA
CEMAGREF	Institut de recherche pour l'ingénierie de l'agriculture et de l'environnement, France
CERAAS	Centre d'étude régional pour l'amélioration de l'adaptation à la sécheresse, Senegal
CERF	Centre d'étude, de recherche et de formation, Réunion
cM	centimorgan
CFCS	Carribean Food Crop Society
CMO-Sugar	Common Market Organisation in the sugar sector
CNASEA	Centre national pour l'aménagement des structures des exploitations agricoles, France
CNEARC	Centre national d'études agronomiques des régions chaudes, Montpellier, France
CNES	Centre national d'études spatiales, France
CRB	Centre de ressources biologiques
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CTC	Centro de Tecnologia Canavieira, Piracicaba, Brazil
CTCS	Centre technique de la canne et du sucre, Le Lamentin, Martinique
CTICS Guadeloupe	Centre technique interprofessionnel de la canne et du sucre, France, Guadeloupe
CTICS La Réunion	Centre technique interprofessionnel de la canne et du sucre, Saint-Denis, Réunion
CTSR	Comité technique de suivi des récoltes

CUMA	Coopérative d'utilisation de matériel agricole en commun
DAF	Direction de l'agriculture et de la forêt, France
DEA	Diplôme d'études approfondies (prerequisite diploma for PhD), France
DESS	Diplôme d'études supérieures spécialisées (1-year postgraduate diploma), France
DOCUP	Document unique de programmation (France, DOM)
DOM	Département d'outre-mer (French overseas department)
EAGGF	European Agricultural Guidance and Guarantee Fund
EDF	groupe Electricité de France
ENITA	Ecoles nationales d'ingénieurs des travaux agricoles, France
ERIC	enterobacterial repetitive intergenic consensus
ESALQ	Ecole supérieure d'agriculture Luiz de Queiroz, Brazil
EST	expressed sequence tag
ETA	entreprise de travaux agricoles
FDGDON	Fédération départementale des groupements de défense contre les organismes nuisibles aux cultures, France
FOFIFA	Centre national de la recherche appliquée au développement rural, Madagascar
FPRTD	Framework Programme for Research and Technical Development (EU)
GIS	geographic information system
GPS	global positioning system
IC-PCR	immunocapture - polymerase chain reaction
ICSB	International Consortium for Sugarcane Biotechnology
IFAD	International Fund for Agricultural Development
IGN	Institut géographique national, France
INA-PG	Institut national agronomique Paris-Grignon, France
INRA	Institut national de la recherche agronomique, France
INSAT	Institut national des sciences appliquées de Toulouse, France
IRD	Institut de recherche pour le développement, Montpellier, France
ISSCT	International Society of Sugarcane Technologists
IUP	Institut universitaire professionnalisé, France

IUT	Institut universitaire de technologie, France
KSC	Kenana Sugar Company, Sudan
LEGTA	Lycée d'enseignement général et technologique agricole (France)
MSIRI	Mauritius Sugar Industry Research Institute, Mauritius
NDVI	normalized difference vegetation index
NRPS	nonribosomal peptide synthase
OECS	Organisation of Eastern Caribbean States Secretariat
ORMVAG	Office régional de mise en valeur du Gharb, Morocco
PCA	principal component analysis
PCR	polymerase chain reaction
PCSI	Projet commun des systèmes irrigués, Réunion
PKS	polyketide synthase
PRAM	Pôle de recherche agronomique de la Martinique (CEMAGREF, CIRAD, INRA and IRD)
QTL	quantitative trait locus
REP-PCR	repetitive extragenic palindrome - polymerase chain reaction
RFLP	restriction fragment length polymorphism
RT-PCR	reverse transcription - polymerase chain reaction
SASRI	South African Sugar Research Institute, South Africa
SASTA	South African Sugar Technologists' Association, South Africa
SAU	surface agricole utile (usable farm area)
SICA	Société d'intérêt collectif agricole
SICADEG	Société d'intérêt collectif agricole et de développement économique de la Guadeloupe
SIMA	Salon international du machinisme agricole, Paris, France
SMS	short message service
SOGREAH	Société grenobloise d'études et d'applications hydrauliques, France
SOSUCO	Société sucrière de la Comoé, Burkina Faso
SPOT	Satellite pour l'observation de la Terre (earth observation satellite)
SPV	service de la protection des végétaux, France
SRI	Sugarcane Research Institute, Tanzania

SSR	single sequence repeat
SUCEST	Sugarcane Expressed Sequence Tag Project (database on partial sugarcane gene sequences)
SUCRETTE	projet de suivi de la canne à sucre par télédétection
TBIA	tissue blot immunoassay
TPRI	Tropical Pesticides Research Institute, Tanzania
UAG	Université Antilles-Guyane, Pointe-à-Pitre, Guadeloupe
UFR	Unité de formation et de recherche (training and research unit in French universities)
ULM	microlight aircraft
UMR BGPI	Unité mixte de recherche Biologie et génétique des interactions plante-parasite, CIRAD, Agro.M, INRA, Montpellier, France
ULCOS	European Ultra Low CO_2 Steelmaking project
UMR BGPI	Unité mixte de recherche Biologie et génétique des interactions pour la protection intégrée, CIRAD, Agro.M, INRA, Montpellier, France
UMR PIA	Biology and Genetics of Plant-Pathogen Interactions joint research unit, CIRAD, Agro.M, INRA, Montpellier, France
UMR PVBMT	Plant Communities and Biological Invaders in Tropical Environments joint research unit, CIRAD, Université de La Réunion, Réunion
UMR TETIS	Spatial Information and Analysis for Territories and Ecosystems joint research unit, CIRAD, CEMAGREF, ENGREF, Montpellier, France
UPR	Unité propre de recherche (internal research unit, CIRAD)
URP SCRID	Sustainable Farming and Rice Cropping Systems cooperative research unit, CIRAD, FOFIFA, Université d'Antananarivo, Madagascar
VCAT	Volontaires civils à l'aide technique (technical support volunteer), France
WICSCBS	West Indies Central Sugar Cane Breeding Station, Barbados
WISBEN	West Indies Sugarcane Breeding and Evaluation Network, Barbados
WIST	West Indies Sugar Technologists
YSRI	Yunnan Sugar Research Institute, China

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