FOOD AND AGRICULTURAL RESEARCH COUNCIL

PROCEEDINGS

THIRD ANNUAL MEETING
OF
AGRICULTURAL SCIENTISTS

REDUIT, MAURITIUS, 17-18 NOVEMBER 1998

October 1999
PROCEEDINGS

Third Annual Meeting of Agricultural Scientists

University of Mauritius
Réduit, Mauritius, 17 - 18 November 1998

Organised by
The Food and Agricultural Research Council (FARC)

in collaboration with
The Agricultural Research and Extension Unit (AREU)
The Agricultural Services, Ministry of Agriculture,
Food Technology and Natural Resources
The Albion Fisheries Research Center (AFRC)
The Faculties of Agriculture and Science,
University of Mauritius (UOM)
The Mauritius Sugar Industry Research Institute (MSIRI)

Sponsored by
The Food and Agricultural Research Council

Edited by
J A Lalouette, D Y Bachraz and N Sukurdeep

October 1999
SUGGESTED CITATION:


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ISBN
PARTICIPATING INSTITUTIONS

Agricultural Research and Extension Unit (AREU)
Réduit Mauritius
Telephone (230) 464 4876  Fax (230) 464 8809  e-mail areu@bow.intnet.mu

The Agricultural Research and Extension Unit functions under the aegis of the Food and Agricultural Research Council as from July 1995. The main objective of AREU is to serve its clients through excellence in cost-effective high quality research and extension and to meet the policy requirements of government. AREU has responsibility for livestock and all crops excluding sugarcane.

Agricultural Services, Ministry of Agriculture, Food Technology and Natural Resources
Réduit Mauritius
Telephone (230) 454 1018  Fax (230) 464 8749

The Agricultural Services of the Ministry of Agriculture, Food Technology and Natural Resources started life as the Department of Agriculture in 1913 itself taking over from the Station Agronomique created in 1893. It is the regulatory body of the Ministry and provides a number of services to the agricultural community.

Albion Fisheries Research Centre (AFRC)
Albion, Petit Rivière, Mauritius
Telephone (230) 238 4100  Fax (230) 238 4184  e-mail fish@intnet.mu

The objectives of the Albion Fisheries Research Centre are to carry out research and development activities with a view to increasing knowledge on fishery resources within the fishing limits of Mauritius and to provide a basis for their sustainable development and management.

Food and Agricultural Research Council (FARC)
Réduit Mauritius
Telephone (230) 465 1011  Fax (230) 465 3344  e-mail farc@intnet.mu

The Food and Agricultural Research Council was created in 1985. Its main objective is to promote, harmonise and co-ordinate research activities in agriculture, fisheries, forestry and food production in line with government policy and to ensure that the farming community draws the maximum benefits from such research.

Mauritius Sugar Industry Research Institute (MSIRI)
Réduit Mauritius
Telephone (230) 454 1061  Fax (230) 454 1971  e-mail M.S.I.R.I.@msiri.intnet.mu

The Mauritius Sugar Industry Research Institute is a statutory body created in 1953 with mandate to promote by means of research and investigation the technical progress of the sugar industry. It also carries out research on foodcrops that are grown in association with sugarcane.

University of Mauritius (UOM)
Réduit Mauritius
Telephone (230) 454 1041  Fax (230) 454 9642  e-mail mobhai@uom.ac.mu

The University of Mauritius was founded in 1965. While training remains one of its important mandates, it also focuses on research in diverse areas which include agriculture and allied subjects.
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FOREWORD

This third Annual Meeting of Agricultural Scientists of Mauritius (AMAS), formerly organised as part of the World Bank assisted Agricultural Management Services Project is now funded by the Food and Agricultural Research Council.

It was decided to continue encouraging younger scientists from the five main agricultural research institutions namely the Agricultural Research and Extension Unit, the Agricultural Services of the Ministry of Agriculture, Food Technology and Natural Resources, the Albion Fisheries Research Centre, the Sugar Industry Research Institute and the University of Mauritius to present papers at this meeting. As a result thirty two papers were received and they are published in the proceedings. In addition five papers presented during poster sessions are also included in the proceedings. The keynote address is dedicated to the memory of late Mr Maurice Paturau, Coordinator of the Joint Economic Council.

We are most grateful to the staff of FARC and to all those who in one way or another have contributed to the success of the meeting.

Jean Alain Lalouette
Director General
WELCOMING ADDRESS

Alain Noel  G.O.S.K., C.B.E.

CHAIRMAN, FARC

The Honourable Minister of Agriculture, Food Technology and Natural Resources
Excellencies, of the Diplomatic Corps
Members of the National Assembly,
The Permanent Secretary, Ministry of Agriculture, Food Technology and Natural Resources
Distinguished Guests,
Fellow scientists
Ladies and Gentlemen

I have pleasure, again this year, to welcome you to the annual meeting of agricultural scientists (AMAS) organised by the Food and Agricultural Research Council, in partnership with the Agricultural Research and Extension Unit, the Agricultural Services, the Mauritius Sugar Industry Research Institute, the University of Mauritius and the Albion Fisheries Research Centre, which I am pleased to welcome among us. This is the third meeting of its kind, and as planned, is set to become an annual feature.

This gathering provides a good opportunity for Agricultural Scientists to meet one another and share their research results with the agricultural community. I am pleased to record the successful response we have had to the call for papers. It is neither reasonable nor desirable to present all the papers received; otherwise this two-day meeting would have been unduly hectic or variable in quality. I have to thank members of the refereeing team who have helped us in the selection of papers. It is our objective to continually raise the standard of papers presented at future conferences. AMAS has so far been opened to local scientists but it is proposed to give it a regional and eventually an international touch.

C'est avec plaisir que nous accueillons parmi nous le représentant du CIRAD de la Réunion qui nous fera un exposé sur la recherche agricole à la Réunion. Je souhaite la bienvenue à Monsieur Bernard Reynaud, et espère que ce n’est que le début d’une longue et fructueuse coopération entre nos institutions.

Our keynote address this year is dedicated to Maurice Paturau whose memory we wish to honour for his contribution to scientific research related to the sugar industry, and particularly its by-products. The subject of this address “Sugar cane and its Co-products” pays tribute to his efforts in this field. It is with great pleasure that I welcome Dr Oscar Almazan, General Vice Chairman of the International Society of Sugarcane Technologists (ISSCT), and President of the Cuban Society of Sugarcane Technologists, to deliver this lecture. I am grateful that he has accepted our invitation and has travelled from Cuba to be our guest.

A special word of thanks to the organising committee, which has spared no effort to make this conference a success.

Ladies and gentleman, Thank you for your presence at this meeting.

AMAS 1998. Food and Agricultural Research Council, Réduit, Mauritius
MINISTER'S ADDRESS

Dr. The Honourable Arvin Boolell
Minister of Agriculture, Food Technology and Natural Resources

I am pleased to be associated with the Third Annual Meeting of Agricultural Scientists.

The results of your deliberation will undoubtedly influence many decisions and policies related to agriculture and will certainly be a major determining factor when the governing boards of the different institutions represented here decide to shape up their action plan for coming years. Your task is a noble one. You are called upon to contribute directly to nation building, in raising levels of nutrition and the standards of living, in securing improvements in the efficiency of the production and distribution of all food and agricultural products. However, we have to ensure that all members of the agricultural community, both large and small, both rich and poor share the benefits of the application of your research.

In this regard, the synergy private-public sector is of vital importance. Your presence, ladies and gentlemen, confirms your commitment and interest in research undertaken by our national institutions. The results of the research, their implementation and the feedback from the grassroots will undoubtedly create the much-needed public-private sector synergy.

It is befitting to attribute the keynote address to be delivered by Dr Almazan to the late Maurice Paturau. Mr. Paturau will be remembered as a bold innovator, and a renowned scholar.

It is certainly necessary that new and effective action should be carried out using the relative limited means available to us. For utilising scarce and limited resources allocated to research, we need to tread cautiously and adopt a pragmatic approach. Overlapping and duplication of research should be avoided at all costs. Research must be based on a careful identification of those areas, which show enough promise for improvement in both the medium and the long term. All of us reckon that the ultimate impact will depend on the overall research facilities. Priorities should be directed not only to national needs but also to our neighbours in the region. I welcome the participation of scientists from La Réunion. My hope is that the next meeting of AMAS shall be enriched by the participation of the Indian Ocean Rim and SADC countries. This action will go a long way in consolidating regional solidarity.

We, in this region, must be aware of the limits and constraints to our research capacity. We need to identify our requirements and to mobilize resources for institutional and manpower development. The activities within existing bilateral and multilateral regional cooperation networks and the establishment of additional ones should help to make optimum use of scarce research resources as it is not possible for each single country to cover entirely all its research needs. In all these fields, Government looks to the scientific community gathered here to provide guidance for its future action.

The myriad of institutions involved in research in Mauritius has to develop a strategy paving the way for Mauritius to be reckoned as a knowledge base in science and in agriculture in the region.

We must all gear our programs to accommodate the opportunities, which Mozambique is presenting to us. Our investors there need scientific backup. In this regard, linkages and working relationships have to be established urgently with sister institutions of Mozambique. Let me recall that the Mozambique issue is a national issue and a collaborative effort of all our institutions in this direction is crucial.

My other humble request to agricultural scientists is to emphasize approaches which are not capital intensive and to give due attention to research priorities such as stability of production and secondly to tolerance of crops to the climatic and environmental stresses and changes in the wake of the global warming up.
In the past, the benefits of research and agricultural technologies have been developed and deployed often with little or no consideration of the impact on the agricultural community, their basic needs and income. Problems related to farm households, gender relationships, consumer preferences and similar issues were seldom considered. But the climate of opinion to day has shifted. The prospective impacts of new technologies are matters of strong public concern. There is a strong recognition that the research community should be aware of the likely impact of its new discoveries. The potential socioeconomic consequences of new technologies should be considered when research priorities and goals are formulated. It will therefore be necessary to monitor and assess not only scientific progress and policies but also the socioeconomic impact of new biotechnologies applied in agriculture.

These are some of the considerations, which you may wish to take into account in the action plan of your respective institutions. I know you would be the first to say that agricultural yields and aggregate output should not be seen as our only objectives. Other objectives such as stability of production systems, ecological sustainability, protection of the environment, food quality or social justice are of equal or even higher importance. Research must benefit both the producers and the consumers. Science must assist in overcoming poverty and narrowing the differences in the quality of life of each, the rich and the not so rich. The aim is a better life for all, for present and for future generations.

I wish you a successful meeting and assure you of my support and my keen interest in your results.

Thank you.
THE SUGAR CANE, ITS BY-PRODUCTS AND CO-PRODUCTS

O Almazan, L Gonzalez and L Galvez
Asociacion de Tecnicos Azucareros de Cuba

ABSTRACT

I came here to pay my respect to a man I met twenty five years ago and who became a real institution in the field of sugar cane by-products; a direct and outspoken man, a true scholar in the knowledge of this line who gave the sugar industry the strength and the necessary buffer capacity to overcome its periodic crises. But above all I want to give my respect to a gentleman, to a man of high intellectual integrity and profound humility, a combination that only the very few can have. I came here to honour this good and admired friend in a way he would have liked to be remembered talking about sugar cane by-products. My address: The Sugar Cane, its by-products and co-products, is dedicated to the memory of the very respected and never to be forgotten Maurice Paturau.

Keywords : sugar-cane, by-products, energy-sources, renewable-energy, biotechnology, sugar-industry, diversification

INTRODUCTION

At the beginning of this century world sugar production, from all different sources, amounted to 12 million tonnes and per capita consumption was 8 kg. Production will have grown tenfold and per capita consumption by three times, by the end of this century. Even with the appearance of new sweeteners on the market, sugar is still the most widely used caloric food in all countries, especially among those of lower income. Its outstanding value for health improvement becomes more evident everyday, mainly when it is used in the less refined form.

The international sugar market will show different characteristics in the next century: It will be a deregulated and highly competitive market; exports will be concentrated, with more than 70 percent accounted for by the five leading exporters, the European Union taking the first place. Eighty percent of imports will be made by the less developed countries compared to only 30 percent in 1970. Alternative sweeteners will slowly continue to increase their presence with an expected 16 percent of the market in year 2000 compared to 13.5 percent in 1994 - 95. Prices are forecasted to be at a level of 22 - 27 US cents per kg (10 - 12 US cents per pound) with a total trade volume of 28 - 30 million tonnes in the year 2000. World food demand at the beginning of next century will be twice as much as three decades ago; less developed countries will need to increase their production by one and a half times to simply meet the requirements of their increasing population.

The energy problem is another issue that will have to be faced and will require more emphasis in planning for next century. World energy consumption (Figure 1) has grown to such an extent that what is spent on oil during this decade will be as much as all the expenditures on oil over the last 100 years. It is in this context that the rationality of the sugar industry diversification must be defined. New trends in biotechnology, the search for new materials, the preference for renewable products of natural origin and other development opportunities are emerging that could raise the added value of raw materials from 5 to 20 times, depending on process complexity and efficiency.

In this paper we present a summary of the evolution, present status and strategies for the development of sugar industry diversification.
Sugarcane as a raw material

Sugar cane has one of the most efficient photosynthetic mechanisms, among commercial crops; this allows it to fix almost 2 - 3 percent of radiant solar energy and transform it into green biomass. This high photosynthetic capability also allows it to show a high coefficient of CO\textsubscript{2} fixation, comparable to the moderate climate zone woods. This contributes to the decrease of the greenhouse effect.

From cane harvest and processing, it is possible to obtain 8 products and by-products (Figure 2) which are potential raw materials for the extractive, chemical and biochemical industry. The various sugar-producing countries currently produce more than fifty commercial products.

One hectare of cane may produce 100 tonnes of green matter every year, which is more than twice the agricultural yield of most other commercial crops. Its total dry matter content has a fuel equivalent of about 10 to 20 tonnes of oil. As metabolic energy carrier for animal feeding, each cultivated hectare delivers 75 000 million calories each year, equivalent to more than 8 times the yield of other fodder crops (Figure 3).
A special attention in the diversification strategy must be given to the efficient use of the energy potential of sugar cane, which may be transformed into approximately 1 tonne of oil equivalent for every tonne of sugar produced. A typical (traditional) sugar cane factory uses inefficiently all the available energy in its bagasse but it has been shown that with a properly designed process, oriented to energy saving, it is possible to operate with only 50 percent of that energy. Sugar cane processed using chemical and biotechnologies, can produce a high number of products, and is surpassed only by those obtained from petrochemistry. Practically all products and by-products obtained from sugar cane may become substrates for liquid or solid-state fermentation processes; using available second and third generation biotechnology a significant number of production processes could be developed. The agro industrial character of sugar cane processing allows for an industrial development in which all available wastes and resources could be managed profitably while avoiding pollution of the environment. Sugar cane producing countries, have a significant advantage in possessing a renewable raw material, which can be used in human and animal feeding, and in the production of basic chemicals, with a yield not equalled by any other plant. Furthermore, sugar cane has energy delivering capacity equivalent to five times that used by the crop. All these factors taken together and the possibilities offered by further genetic improvement, turns sugar cane into the ideal crop for the next century.

**Bagasse fibre as a raw material**

Bagasse obtained as a by-product of sugar cane processing, is composed of fibre, pith, non-soluble solids and water; fibre represents about half of all components, and includes cellulose, hemicellulose and lignin of low molecular weight. Its morphological structure is not strong in comparison with other fibres like those of wood; its advantages are shown during chemical and mechanical treatments, since it does not have to be submitted to severe processes. Another important advantage is that it is directly obtained and concentrated in the sugar factory as a process by-product, thus simplifying handling and transport operations. Every year, more than 200 million tonnes of bagasse are obtained together with sugar, in all cane producing countries, 95 percent of which is used as fuel in the mills, which represent a saving of about 40 million tonnes of oil.

Pulp and paper, boards, furfural and animal feeds are among the main products obtained from bagasse not used as fuel. The most widespread use of bagasse around the world is in the production of pulp and paper. There are about 90 factories in all, of which three-quarters are established in Asia, Oceania and the Middle East, delivering up to 2.5 percent of the total world production. Intense exploitation of wood has caused depletion of forest reserves. This has triggered a trend to decrease this exploitation, to implement reforestation policies and renew interest in tropical woods and annual plants to be used in combination with traditional wood fibres. It becomes evident that it will be necessary to rely on other fibre sources to fulfil the forecasted demands for the next century. Among alternative fibres, it is accepted that bagasse is one of the best due to its quality, cost and renewable character.

Bagasse fibre can be used at present as an important component in printing and cultural paper, but its use for industrial paper is still limited. One hectare of sugar cane can produce, annually, about five
tonnes of fibre for pulp and paper production, twice as much as that produced by one hectare of wood with the same management. The renewal period is fifteen times shorter for sugar cane.

New developments in pulping are expected to include a first step consisting of a microbiological treatment for fibre preservation and its partial or total delignification in the unavoidable storage stage. Consequently the rest of the process will have lower energy and chemicals demands. Bleaching processes will turn to gas phase, aiming for better yields and the elimination of pollutants in current processes.

Mechanical and thermo-mechanical pulping will become more popular in paper production with a decreasing share of traditional chemical pulps. More chemicals will be used in industrial paper production in order to obtain the desired specific properties. The paper industry will maintain its trend of increasing the waste paper recycling in order to reduce fresh fibre addition in the feed and as a contribution to the rational use of natural resources. New technologies will decrease the present demand of water to one third, reducing in the same proportion the pollution load of the wastes.

Fibres are also used for the production of bagasse boards, a production which is expected to increase for the same reason because of the need to preserve forest reserves, promoting the search for new alternatives for both types, particle and fibre boards and new types as the MDF boards. Moulded elements, produced by similar technologies, as those of boards will fulfil the quality requirements of a great deal of industry and home products.

### Composites of natural fibres

The composite is a mixture of dispersed particles held together by a bonding agent of inorganic or organic origin.

Bagasse is not only a renewable source of natural fibres, but can also be transformed into furfural, which may be the starting point of a large number of resins.

There are composites of natural fibres for the automobile industry, for textiles, for construction materials, with inorganic and organic matrices and more recently, recycled composites made of natural fibres bonded with thermoplastic polymers.

Boards and moulded elements will show specific properties for different purposes: furniture, liners, walls or construction forms. These products will be designed and produced in such a way that they will be able to substitute wood in up to 90 percent of its uses. They will be finished with radiation-polymerised resins, which will result in a much better quality than that reached today and an improved surface resistance. These polymers used for bonding and finishing may be produced from other products and by-products such as furfural or sucrose; the lignin present in bagasse can also be used as the bonding agent. Properties of lignin will be used for fulfilling demands of moulded elements for domestic products, furniture, the automobile industry, and packing materials.

### Chemical and biotechnological development of cane sugar by-products

Most chemical firms have based their production mainly on petro-chemistry, while other alternatives like those offered by sugar cane, have received much less attention. The economical causes for this situation are expected to change in the future.

Considering all of these sources, different possible alternatives for the production of organic and speciality chemicals and related products could be mentioned.
Biotechnologies of second and third generation have made available conventional and new
technologies for the production of: amino acids, vitamins, organic acids, solvents, microbial polymers,
proteins for human and animal consumption, enzymes for industrial use, alcohol and co-products
industry and such microbiological processes as: silage, biologic treatments of lignocelulosic residues,
biopulping and biobleaching processes, anaerobic digestion of waste streams, and other alternatives. In
addition, more sophisticated technologies are available for their application in the pharmaceutical
industry. It may be considered that all sugar cane by-products could be used as substrates for liquid or
solid-state fermentation opening a wide range of possibilities for production based on biochemical
processes.

Alcohol as automotive fuel

Brazil transforms sugar cane into about 12 x 109 litres of alcohol, one fifth of which, in anhydrous form.

The Proalcohol Program reached its 20th anniversary facing a crisis of official support, after an investment of
USD 11 000 million and decreasing imports of gasoline of more than USD 27 000 million during the past two
decades.

Out of 348 distilleries only 298 are still in operation, resulting in the importation of 1 000 million litres of ethanol
and 800 million litres of methanol.

The supporters of the Proalcohol Program constitute a powerful lobby using the very reasons which led to the
creation of the program: the economic value of this industry and its contribution both as a renewable source of
energy and as a solution to environmental pollution in big cities.

No matter what will be the outcome of this conflict, it will bear an influence on both the alcohol and sugar
markets.

The development of a chemical industry from ethanol or alco-chemistry, as an alternative or complement
to petro-chemistry could allow the production of basic products in all industry branches. The two most
developed alternatives are those following the ethylene and acetaldehyde paths. The first one produces
a great variety of plastic materials in great demand and the second one develops acetate compounds,
which are the basis of the paint and varnish industries. Even when high efficiency and relative low cost
in petro-chemical production are perfectly known, the complexity of plants, their economies of scale
and high investment costs set true limits in those countries with insufficient financial resources, limited
markets or technological development, and little or inexistent oil resources. Alco-chemistry
technologies are available and operating at industrial scale in some countries. A waste product from
alcohol production: fusel oil, a mixture of isomers of amylic and propylic alcohols, could be recovered.
Isoamylic alcohol, amylic alcohol, n-butanol and other compounds may be separated through
distillation showing some economical advantages due to low costs. Furfural is an aldehyde produced
by the acid hydrolysis of the pentosans present in different crops.Cane bagasse is one of the best raw
materials for this production. Low toxicity of fufural makes it a valuable product for the chemical
industry from which the following could be derived : resins and plastics, pharmaceuticals,
furfurylalcohol and its resins and monochloroacetic acid, herbicides, tetrahydrofurfurylic alcohol and
maleic anhydride, tetrahydrofuran.
Based on sugar cane by-products some alternatives for herbicides production could be mentioned: the first from furfural, and some others based on acetic or propionic acids possibly derived from furfural or alcohol production wastes. The option of new herbicide production starting with furfural has been studied for many years. The synthesis of different products, which passed the screening tests with positive results, has been successfully achieved. The results however can only be considered in the medium or long term because of the high costs of development. Acetic acid obtained from furfural distillation, and propionic acid from alcohol distilleries wastes may become, in the short term, raw materials for conventional products such as 3-chloroacetic acid, monochloroacetic acid or chloropropionic acid. Cellulose in bagasse could be used for the development of a cellulose based chemical industry. Cellulose fibres obtained from bagasse, showing high modules of wet resistance, could substitute up to 60 percent of the fibres derived from cotton cellulose used today in commercial textiles.

Fibrana production processes use directly wet pulps and accelerated ageing of alkali cellulose. Fibres are treated in processes, which allow them to reach high modules of wet resistance, similar to those of cotton. Based on chemical pulps, other high demand by-products of cellulose can be produced such as: cellophane, carboximethylcellulose, cellulose acetate, cellulose nitrate, cellulosamide, chromatographic bases and others. Most of these products would be manufactured in a combined way through the integral use of the installations.

For the production of chemicals through thermo chemistry there are three main options: gasification, pyrolysis and liquefaction. Studies up to the present show that the most interesting alternative is that of gasification for production of synthesis gas as a way which can be converted to methanol, ammonia and ethylene. At medium and long terms, some of these products may be feasible but these alternatives are still in an experimental stage.

Lignin is the second most abundant substance in nature, and at the same time one of the least exploited up to the present. A great potential exists for its use in the chemical industry. It is technologically feasible to obtain phenols for production of adhesives, resins, fungicides, veterinary products, insecticides, and carbon. Lignosulphonates are present in black liquors of sulfite processing. It is a very important product in the artificial board industry as a filler and/or additive in the urea-formaldehyde resin, and for reducing costs and improving some board properties.

**Sucrochemistry as an alternative use of sugar**

During the nineteen forties, technological processes using sucrose as raw material for chemical production started to be referred to as *sucrochemistry*. In the last five decades, about 10 000 technically feasible products have been developed from sucrose at laboratory and pilot plant scale. Only about one hundred have also demonstrated their economic feasibility and are being produced on a commercial scale.

Due to its high production level as a commercial, crystalline product, sucrose is one of the most interesting substrate for the development of new chemical and microbiological technologies. The presence of 8 hydroxyl groups allows broad possibilities of chemical bonding becoming a potential source for the production of chemicals with quite different properties, through degradation, synthetic and microbiological reactions. Through controlled degradation reactions, it is possible to obtain an important number of chemicals. However only through catalytic hydrogenation it has been possible to produce such important commercial products as: fructose, sorbitol and mannitol. Through chemical synthesis and based on the high solubility of sucrose in water and the presence of the high number of hydroxyl groups, it has been possible to produce: ethers, esters from fatty acids, polymers and resins, among the most important, some of which have reached commercial production. These routes show the drawback that reaction products are not stable in those solvents in which sucrose itself is, turning separation and purification stages very complex and expensive.

*Sucrose ethers* are obtained by the substitution of hydrogen ions by alkyl or aryl groups. The properties of resulting compounds are not attractive from a commercial point of view, limiting the development of this alternative; only urethanes have found an industrial use and a market. Used in rigid foams (polyurethane) they offer good potentiality based on their prices and quality.
Fatty acid esters require most intense research work and a significant number of different processes. Some American, Japanese, English and French firms deliver different products to the market, turning this alternative as the most important, with the highest commercial potential.

Polyesters Of Fatty Acids are receiving special attention in the last years because of their use in hypo caloric diets, and as blood cholesterol depressors. Some sucrose esters have shown their properties, when used in low concentration, as antimicrobial agents, inhibiting bacterial growth. Cosmetic formulation with sucrose esters has had good acceptance, due to their dermatological properties and their innocuity. In the same way, they have been used in biodegradable detergents, for widespread use extracting spilt oil from the sea and other aqueous deposits. The alternative of microbial transformations of sucrose molecules allows the production of different biopolymer such as dextran and xhantan; both are products used in foods, pharmaceuticals and in oil extraction. The biopolymer polyhydroxibutirate showing similar properties to those of polypropylene has not been able to compete with the latter due to high production costs.

Based on sucrose, some other sweetening agents showing special properties have been obtained becoming potential alternatives for sucrose. Among the most important the following could be mentioned.

Chlored chemicals obtained through selective substitution of hydroxyls with chlorine atoms are often products sweeter than sucrose. But there are others, which are extremely bitter, showing specific properties. The use of these compounds awaits approval by medical authorities.

Leucrose is a sucrose isomer with less sweetening power, innocuous, acceptable by diabetics, approved as a human food. It is also used as basis for production of special purpose tensoactives.

Sucralose was developed two decades ago through a modification of the molecular structure of sucrose. It is 600 times sweeter and shows similar flavour characteristics. From the point of view of human health it does not stimulate insulin formation, and it is eliminated from the human body without showing chemical changes, thus being a non-caloric food.

L. sugars or "lefties" as they are also called, are obtained through a change in hydroxyl groups. Their taste is close to that of sucrose while showing no calorific value, as they are not metabolised, and proceed through the intestines without chemical changes. Their production costs are high, and they have yet to complete tests for medical approval. Another product reached as sugar modification is isomalt, showing functional properties close to those ones of sucrose, with little commercialisation in Europe.

**Substitute sweeteners for sugar**

These products, born last century, show two main features: they are competitive in price and due to their low calorific value are good controllers of human weight.

Those nutritional substitutes may be sacharides or polyalcohols, which supply little or no energy to the organism while showing a sweet characteristic flavour. Those that are non-nutritional may be of synthetic or of natural origin; not giving up energy, they are used in beverage, food, and dairy products industries.

Tendency to use in sweetening; in mixtures however limited use, if production costs are not reduced.

It can be generally stated that sucrose alternative molecules, to be used as raw material for chemical production maintain the interest of researchers and producers due to the variety of applications that the products may have. Out of the three ways of reactions that sucrose could be subjected to degradation, chemical and microbiological, the latter appears to be the most interesting for the development of sucrochemistry.
Sources of animal feeding

The food, energy and environment problems are among the priority issues for the next century. Sugar cane production, followed by a rational diversification strategy, might have a significant place in this context because of its characteristic as a highly efficient system for solar energy fixation and transformation into green matter. This biomass is usable for energy and feeding purposes, while saving non-renewable sources of energy; it has therefore a positive CO$_2$ fixation balance. This statement is relevant to countries with tropical and subtropical climates where sugar cane can be grown and where socio-economical, technical and agricultural considerations will probably determine the optimal use of cereals mainly for direct human consumption. The indiscriminate extrapolation of feeding systems of moderate climate conditions to tropical countries will most probably result in a sub-optimal solution in the latter.

Under tropical conditions, feeding systems might rely on sugar cane as a source for 60 - 80 percent of ruminant and swine feeding requirements; this is true only if they are adequately supplemented with other products, which must be imported or made available locally. Sugar cane has a high percent of fibre with a low digestibility, which becomes a limitation for its use in monogastric animals. To overcome this deficiency and make an optimal use of the whole cane, alternatives have been developed for the latter's separation into three basic components: the crop wastes that may be used in its natural form or treated in a simple way for feeding bovines; the soluble sugars present in the juice to be used for poultry and swine, and lastly the fibre, after being subjected to simple treatments to raise its digestibility, to be given to ruminants.

### Cane for animal feeding: main raw material alternatives

| Whole cane conditioned for its direct consumption |
| Agricultural wastes as they are produced |
| Industrial by-products: bagasse, cush-cush, pith, C molasses and mud (cachaza) Process intermediate products, B molasses and diluted juices |
| Sugar as the commercial product, or of lower quality, or damaged |
| Proteins produced from fermentation of molasses or recovered in distilleries |

The best way to use sugar cane for animal feeding is to use sugar, fibre or green mass depending on the species ability to more efficiently convert these products. The industrial processing of cane in the sugar factory, and the possibility of obtaining different products is probably the alternative showing the highest potential added value.

### Feed characteristics required by different kinds of animals

**Cattle:** Feeding may be based on fibres either from harvest wastes or from pith or bagacillo treated to increase their digestibility. Non protein nitrogen may be used up to a given level. Quality requirement of feed is not so high compared with other species.

**Swine:** Monogastrics show higher quality requirements of feed, not being able to metabolise fibres. An energy source must be provided such as final molasses which has its limitations or intermediate molasses; fodder yeast may be used as protein source.

**Poultry:** It is the kind of animal with the highest and most complex requirements for feed quality. The energy sources used must show high values per unit weight and protein must be true protein showing a balanced amino acid profile. All vitamins required must be supplied.

An integral analysis of the main kinds of animals shows that the highest conversion of energy is accomplished in the production of swine and cow milk. In the case of protein conversion, meat production through bovines is the least efficient. Poultry show the fastest response with average mortality rates, but with high quality requirements in food, and the highest level of care. Swine show
the best conversion of food, productivity in newborn, high rates in weight increase, and a high yield of meat in the slaughterhouse, besides the possibility of producing meat derivatives showing higher added values. Ruminants become interesting to exploit the availability of low digestibility foods showing low values of true protein, even though daily gains will be lower than those obtained in moderate climates.

The final decision of which alternative to follow in the production of meat and milk will be settled not only through the rational use of sugar cane, but also taking into account the local conditions to get the supplements required in the feeds, their prices and the markets to which the products will go.

**Organic agriculture and sugar cane**

The demand for agricultural products and foods obtained by ecological methods increase every day, building up new markets for those higher priced products. These products are obtained through what is known as *Biological* or *Organic Agriculture*. This system implies solutions to avoid the Earth's pollution, to provide better health conditions for producers and consumers, and to protect human life particularly in rural populations. A new food industry for the production of nutritive and healthy foods is emerging. Organic foods show maximum quality from the points of view of nutrition, and flavour, and have the better appearance. This system protects the environment and preserves fertility of soils and genetic diversity, through the optimum use of renewable resources, thus enabling sustainable agricultural development while avoiding the use of synthetic chemicals. Among the main practices for supporting this approach the following could be mentioned: bio-control, use of bio-fertilisers, green fertilisers, crop rotation, and composting.

Sugar cane by-products may find use in each one of these methods, as raw materials of different kinds and properties suitable for biotechnological transformation into valuable products, which can be used in cultivation of sugar cane and other crops. Interest in bio-control has increased lately, mainly due to the ever-increasing policies restricting the use of pesticides, and the search for techniques more friendly to the environment. Microorganisms may be used not only against other non-desirable microorganisms, but also against insects and plagues.

Experience exists in Cuba with the application of different agents for bio control in general agriculture, and especially in sugar cane, it encompasses the control of cane borer with the *Lixophaga* fly, and recently, the use of *Trichoderma* against most common fungus infections. At present, four different types of bio fertilizers are produced in Cuba; these are: *Azotobacter*, *Rhizobium*, *Bradyrhizobium*, and *Azospirillum*, the latter showing the best results in sugar cane, with yield increases of the order of 50 percent, depending on soil type and cane variety. Under Cuban conditions, the high level of harvest mechanisation, the industrial concentration of harvest wastes at the cleaning stations, and the availability of filter mud (*cachaza*) and bagasse at the factory makes composting very relevant. An adequate balance in formulation guarantees a complete and correct degradation of organic matter and substances to materials of humic nature.

Among micro-organisms producing positive effects in their interaction with plants, there are those able to produce growth regulators or phytohormones; these are chemical substances contributing to control the normal development of plants through a very fine balance between growth and the factors controlling it. Indoleacetic acid is used today in agriculture for different purposes, mainly in micro propagation of crops, particularly in sugar cane. Gibberellins, in particular gibberellic acid, are without doubt, the most important growth regulators produced by microorganisms, being given their production at world level and their broad application in agriculture. There are reports concerning their use for increasing yields in sugar cane, even though their use is not currently widespread for that purpose.

**Sugar cane as energy source**

Sugar cane dry matter when burned, produces 4000 Kcal per Kg (7200 Btu / lb.). One hectare of sugarcane can produce about 100 to 200 millions Kcal per year equivalent to about 10 to 20 tonnes of oil. Several studies have shown that the sugar cane industry can deliver not only surplus bagasse through efficient generation and use of steam, but also a surplus of 60 to 120 kWh of electric power per
tonne of cane, which can be delivered, to the grid. Most cane sugar factories all over the world use 550 to 650 kg of steam per tonne of crushed canes. For many years beet sugar factories, with a very similar process to that in use by cane sugar factories have been known to use about 320 kg per tonne of beet. Use of multiple bleeding in evaporation stations for heating and boiling, a high number of evaporation stages, up to six or even seven, the substitution of throttling valves by other systems, are solutions enhancing energy efficiencies. This has been tried in cane sugar factories, and values of the order of 370 kg of steam per tonne of cane have been recorded. This decrease in process steam may promote reductions in burned bagasse of about 25 percent. Cogeneration is the cheapest way of delivering surplus electrical power for other industrial uses or to the grid, while also delivering surplus bagasse. Currently, most boilers manufactured operate at a ratio of about 2.2 for steam generated to bagasse burnt (bagasse at 50 % moisture). The efficiencies of these boilers based on low heating values in the range of 80 to 84 percent, are better than those of most existing traditional boilers. Efficient use of process steam, dependent on high steam pressure and temperature in the steam generator, is not common in cane sugar factories with the exception of those in which big amounts of bagasse are used for other purposes. An unavoidable condition for economic development of by-products is to make use of the available co generated electric power while having simultaneously surplus bagasse.

**Diversification as a complement of sugar production**

Industrial production of by-products has not shown a constant, smooth development. It is estimated that at present there are about 800 factories all over the world, most of which have only started operations in the last three decades, and make use of about fifty industrial scale tested technologies. In the last decade a better integration of by-product production with sugar processing has started, in order to benefit from potential advantages in energy use, waste disposal and market penetration. The cultivation of new varieties showing higher yields of green matter for by-products' production has also been explored. The Cuban experience in by-products' development in the fields of raw materials, finishing, complexity of processes and added value can be divided in four phases of which boundaries and extensions are arbitrarily established.

The first phase covers the direct use of raw materials at low processing level.

The second phase integrates those productions using by-products as raw materials and intermediate products of sugar processing, in processes of little complexity leading to end products of special characteristics.

The third phase involves products made by chemical and biochemical changes using second-generation by-products and sugar as raw materials. Properties of products are quite different to those of raw materials from which they were prepared; technologies show medium to high complexity.

The fourth phase generates products obtained from by-products of second and third phase; they are promoters or intermediaries of other processes. Complex chemical and biochemical technologies are involved, the end products showing high added values.

These technological alternatives show that sugar-producing countries can broadly widen the horizon for sugar cane exploitation when following a diversification approach. Based on this reasoning, the main arguments used in the selection of alternatives for different by-products are as follows.

As a first rule, alternatives must be selected with high ratios of selling price to cost of intermediates or by-products used as raw materials. For development of by-products cane varieties should have high fibre content and short development time up to maximum sugar content for fermentation technologies. Whenever conditions allow, manufacture of by-products should derive from integral processes of energy balance and technology. For example the poorest juices of the milling station and the vacuum filter filtrate could be used for fermentation processes, and A and B molasses for cattle feeding.
Closed processing cycles should be adopted in order to make use of most wastes, changing them into useful products while recovering for recycling, most of the water, and hence decreasing the quantity of fresh water used and avoiding pollution. When considering the efficient use of energy in sugar processing, two approaches become evident: co-generation, and efficient use of steam; the latter is more significant when surplus bagasse is required. Benefits of co-generation described before, is the result of efficient steam generation due to higher pressures and temperatures, increasing the availability of thermal energy conversion into mechanical and resulting in a decrease of the specific steam rate index, that is, Kg of steam per kWh.

**Premises in alternative selection**

- Selection of those showing attractive economical results
- Integral layouts of involved technologies
- Efficient use of energy
- Flexible economy of scale
- Priority to animal feeding
- Non pollution of the environment

Considering alternatives for animal feeding, it is important to have installations showing flexible scale economy; maximum available raw materials in the region must be used in order to reduce handling and transportation costs. These materials can change throughout the year, depending on market conditions, but must fulfill required changes in animal diets. The situation is different with other processes having bigger scale economies requiring more complex and capital intensive technologies, such as pulp and paper, bagasse boards, amino acids, citric acid, just to mention a few (Table 1). The example for Cuba is given in Table 2.

By-products manufacture generates wastes, which may increase pollution levels. This can be controlled by adequate use and reuse of process water in addition to the application of the necessary treatments.

In slightly over three decades, the sugar cane by-products production capacity has doubled, involving some 70 factories and nearly 300 facilities, most of them using local technology. Cuba has one of the largest numbers of technologies for manufacture of by-products, as well as the ability to generate new knowledge in this field, which enables her to further develop the product on of new derivatives.
Table 1. Present status of by-product technology development

<table>
<thead>
<tr>
<th>By-Products and Products</th>
<th>Commercial Production</th>
<th>Plant under Construction</th>
<th>Pilot Plant Scale</th>
<th>Laboratory Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop residues</td>
<td>Animal feed, edible mushrooms compost.</td>
<td>Mushroom plant</td>
<td>Silage</td>
<td>Mushrooms</td>
</tr>
<tr>
<td>Filter cake</td>
<td>Compost, animal feed, waxes.</td>
<td>Pharmaceutical wax extract, phytosterols.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sugar</td>
<td>Dextran, ferridextran, glucose, sorbitol.</td>
<td></td>
<td>Jasmonic acid, indoleacetic acid</td>
<td></td>
</tr>
<tr>
<td>Wastes &amp; effluents</td>
<td>Ferti-irrigation, biogas, animal feed.</td>
<td>Biogas</td>
<td>Biogas</td>
<td></td>
</tr>
<tr>
<td>Ashes</td>
<td>Fertilisers.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2: Installed capacities for the production of sugar cane by-products in Cuba

<table>
<thead>
<tr>
<th>Plants</th>
<th>Number of Plants</th>
<th>Installed Capacity</th>
<th>Facilities</th>
<th>Number of Facilities</th>
<th>Installed Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcohol distillery</td>
<td>16</td>
<td>1 800 Mhly⁻¹</td>
<td>Edible mushrooms</td>
<td>10</td>
<td>200 ty⁻¹</td>
</tr>
<tr>
<td>CO₂</td>
<td>3</td>
<td>18 td⁻¹</td>
<td>Molasses-urea</td>
<td>79</td>
<td>600 M ty⁻¹</td>
</tr>
<tr>
<td>Rum distilleries</td>
<td>11</td>
<td>1.2 M boxes y⁻¹</td>
<td>Molasses-urea-pith</td>
<td>36</td>
<td>400 M ty⁻¹</td>
</tr>
<tr>
<td>Fodder yeast</td>
<td>11</td>
<td>110 M ty⁻¹</td>
<td>Pre-digested pith</td>
<td>71</td>
<td>350 M ty⁻¹</td>
</tr>
<tr>
<td>Yeast for human</td>
<td>1</td>
<td>8 M ty⁻¹</td>
<td>Hydrolysed bagasse</td>
<td>1</td>
<td>5 M ty⁻¹</td>
</tr>
<tr>
<td>Particle board</td>
<td>5</td>
<td>180 M m³y⁻¹</td>
<td>Pre-digested pith</td>
<td>11</td>
<td>70 M ty⁻¹</td>
</tr>
<tr>
<td>Fibre board</td>
<td>2</td>
<td>23 M m³y⁻¹</td>
<td>High-protein molasses</td>
<td>11</td>
<td>450 M ty⁻¹</td>
</tr>
<tr>
<td>Paper</td>
<td>5</td>
<td>140 M m³y⁻¹</td>
<td>Garamber</td>
<td>11</td>
<td>100 M ty⁻¹</td>
</tr>
<tr>
<td>Furfural</td>
<td>1</td>
<td>1 M ty⁻¹</td>
<td>Pajumel</td>
<td>8</td>
<td>60 M ty⁻¹</td>
</tr>
<tr>
<td>Dextran</td>
<td>1</td>
<td>400 ty⁻¹</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glucose</td>
<td>2</td>
<td>200 ty⁻¹</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sorbitol</td>
<td>1</td>
<td>200 ty⁻¹</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saccharomyces yeast</td>
<td>10</td>
<td>300 ty⁻¹</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wax</td>
<td>2</td>
<td>50 ty⁻¹</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alpha-amylase</td>
<td>5</td>
<td>50 ty⁻¹</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Development of by-products offers different alternatives from which those better suited for local conditions; available markets and financial conditions should be selected (Figure 4).

**Figure 4** Economic Indices of Selected by-products

Enterprise leaders in industry must approach diversification as a complement of sugar production, improving the exploitation of sugar cane and contributing in this way to the sustainability of sugar economy.